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Special Scientific Report No. 53

HISTORY, DEVELOPMENT, AND PROBLEMS OF ELECTRIC FISH SCREEN

by

Harlan B. Holmes

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HISTORICAL ACCOUNT

Some features of the present status and future possibilities of the electric fish screen can best be understood through a review of the history of the electric screen. Throughout such history the name of Mr. H. T. Burkey must appear more frequently than any other for it appears that it was he who originated the idea of using electricity for this purpose, and throughout its development and application he has been the most active individual.

FIRST PERIOD OF APPLICATION - 1917 to 1925

The earliest reliable records of the electric screen is Mr. Burkey's application for patents in 1917 (No. 1,269,380) and in 1918 (No. 1,292,246).

In 1918 Mr. Burkey demonstrated his screen at the hatchery of the U. S. Bureau of Fisheries at Clackamas, Oregon. No information is available as to the nature of the experiment or who observed it, except that Mr. Henry O'Malley, who later became Commissioner of Fisheries, was favorably impressed. It appears that demonstrations and experiments were started in California at about the same time. (Ref. letter W. H. Shebley to Hugh C. Mitchell, Oct. 4, 1928; also California Fish and Game, 1922).

Also near this time the Game Commission of Yakima County, Washington, became interested in the electric screen. In April 1920 that Commission purchased the right to apply in Yakima County Mr. Burkey's patented screen and any improvements that he might make. Several installations were made at that time in irrigation and power diversions, in both Yakima and Chelan counties.

The exact nature of these early electric screens is not known. Some of the earliest ones were as illustrated in Mr. Burkey's patent No. 1,292,246, in that the electrodes were in the form of several pairs at opposite sides of the waterway. Successive pairs of electrodes were connected to progressively higher voltages, for the purpose of producing a graduated electrical field in the water. A little later (see pictures in Pacific Marine Reviewer, 1921, and Literary Digest, 1921) the electrodes were changed to two rows of iron bars extending across the waterway, with alternate electrodes within each row having the same polarity. Electricity for such screens sometimes was 110 volt A. C. from commercial lines; more commonly it was supplied from a model-T Ford magneto turned by a paddle wheel. Between the magneto and the electrodes a spark coil sometimes was used to increase the voltage.

As far as has been learned, these early screens were not adequately checked for efficiency. The impression of the Yakima County Game Commissioners is indicated by the fact that they were willing to pay $1,500 for merely the patent rights and advice of the inventor for a maximum of 10 screen installations, the only requirement being that the first installation be "as good or better than demonstration device installed at McNatt Station".

A similar attitude is expressed in a report of the Washington State Supervisor of Game and Game Fish (Washington Department of Fisheries and Game, 1923):

> "Early in 1921, we made a survey of several of these fishstops that had been installed by the Yakima County Game Commission and found that they had not yet discovered the exact amount of electricity necessary to prevent the fish from entering the ditches. We placed the experimental equipment in the hands of an electrical engineer who, after spending considerable time and money, made a detailed report to this Department of his findings and recommended that the stop be installed wherever possible.
>
> "If the Department had sufficient funds, we would endeavor to place suitable electric fishstops at the entrance of each large irrigation ditch in the State of Washington. It would cost, in round figures, about $100,000.00 to install these stops but the net results for even a year would pay back the cost.
>
> "While experimenting with this fishstop, we discovered that it requires very little electricity to kill a fish, and we also found that the trout would not enter the charged water. After connecting the current with the electrodes in the tanks which we were using for the experiment, it was found impossible to drive the fish into the charged water more than once."

Quite a different attitude seems to have prevailed in California as indicated by the following article (California Fish and Game, 1922):

> "Several articles have appeared in recent periodicals relative to the perfection of an effective screen utilizing an electric current for use in irrigation ditches. These articles are altogether too optimistic, in the light of investigations made by the California Fish and Game Commission. On several different occasions the apparatus has been given a thorough test and found unsatisfactory. Young fish placed in a ditch for experimental purposes readily ran between the electrodes when the current was not too strong, and were quickly killed by the current as soon as a certain voltage was obtained. Considerable time and money have been expended by the

commission in an endeavor to test and see whether electricity could be used advantageously as a means of screening fish from irrigation ditches. But up to the present time no one has satisfactorily demonstrated that this principle is practical when trout and salmon are to be prevented from passing into large ditches or canals. Further experiments will be made this coming season on an improved method of using the electrodes."

The generally favorable attitude in Washington toward the electric screen seems to have become reversed within a few years. For example, Mr. John N. Cobb, Dean of the College of Fisheries at the University of Washington, in 1922 (Cobb, 1922) expressed a favorable impression; but in a letter dated August 2, 1926 to Mr. J. E. Yates, of the Pacific Power and Light Company, he wrote:

"We carried on some experiments at the College but these did not encourage us in the belief that this was the feasible way to keep fish out of irrigation ditches."

In answer to an inquiry in 1927 he wrote:

"Some years ago we prepared a standard set of plans for this device at the request of our State Department of Fisheries. It is problematical whether this device accomplished the purpose sought... My investigation led me to think that a much safer device would be the rotary fish screen..."

A change in the attitude of the Washington Department of Fisheries and Game is indicated by the following extract from a letter dated June 6, 1926 from Mr. L. E. Mayhall, General Superintendent of Hatcheries, to Mr. Charles R. Pollock, Supervisor of Fisheries:

"I investigated these irrigation ditches three years ago and reported on the inefficiency of the electric fishstops and recommended aggressive action in the way of working out something practical with the irrigation ditch fishstop."

It appears that before 1926 most if not all of the electric screens in the Northwest had been abandoned.

EARLY INVESTIGATIONS, 1921 - 1928

J. H. Siegfried - 1921

In 1920 or 1921 Mr. J. H. Siegfried (1921), Superintendent of Power for the Pacific Power and Light Company, conducted laboratory experiments in which he attempted to find answers to the following questions:

"1. Would the fish be scared away by the electric current?

2. Could sufficient current be sent through water from the mountain streams to keep fish from passing the electrodes?

3. How much current and voltage would be necessary for this purpose?

4. Could a Ford generator furnish this and under what conditions?

5. At what distance would various voltages applied to the electrodes affect the fish?

6. What current would stun a fish so it would float down stream past the stop?"

Although Siegfried did not get complete answers to all his questions he did get some idea of what voltage must be applied to the electrodes to cause the fish to respond or be stunned by it. He also found that with a spark coil in the circuit with the Ford generator there actually was less electrical energy delivered to the water than when the generator was connected directly to the electrodes in the water.

J. E. Yates - 1926

In 1926 Mr. J. E. Yates, of the Pacific Power and Light Company in Portland, Oregon, became interested in the electric fish screen. Through his efforts his company had a trial screen installed at the intake to the Gold Ray power plant on the Rogue River in southern Oregon. This installation was like some of those installed earlier in the Yakima Valley. The electrodes were 1-inch pipes in two rows, those in the second row being staggered rather than in line with those in the front row. Successive electrodes in each row were of opposite polarity. The electricity applied was 60-cycle A. C. This screen was operated only a short time because it was observed to be injuring adult salmon that were leaving the upper end of a fish ladder near the screen.

F. O. McMillan - 1926

Mr. Yates also was instrumental in securing the services of F. O. McMillan, Associate Professor of Electrical Engineering at Oregon State Agricultural College, who conducted experiments at the Oregon Fish Commission's Bonneville hatchery during the summer of 1926. Professor McMillan's report later was published by the U. S. Bureau of Fisheries (McMillan, 1928).

The following are the more important items studied by McMillan:

1. He clearly demonstrated that the voltage gradient required to paralyze a fish by alternating current is dependent upon the length of the fish and the conductivity of the water. Stated in terms somewhat different from those of McMillan, these relations are that to paralyze a salmon of any size the voltage across the fish, in whatever direction the current passes through the fish--whether that direction be lengthwise, crosswise, or other direction--ranges from approximately 3.7 volts when the fish is in very pure water, having a resistance of 10,000 ohms per inch cube, down to approximately 50 percent of that amount for highly-conductive stream water, and 20 percent as much for sea water.

2. He measured the conductivity of the water in fifteen streams in the Northwest and called attention to the fact that the conductivity of water is a function of its temperature as well as its chemical content.

3. He explained the distribution of current and voltage gradient in water between electrodes of different size and spacing.

4. In addition to 60-cycle alternating current, he tried high frequency and continuous direct current. He found high-frequency was not satisfactory and that continuous direct current gave essentially the same results as alternating current.

5. He then applied his findings to several electric fish screen installations in the hatchery ponds.

Upon the basis of his laboratory experiments and applications to screens in the hatchery ponds, McMillan emphasized particularly that the electrodes should be so arranged that in the area in which the fish are expected to encounter the electric field, the lines of flow of electric current will be parallel to the direction of flow of water. When small fish, migrating slowly downstream tail first, enter such an electric field, the electric current passes lengthwise through their bodies and they receive a maximal shock. This is exactly opposite to the arrangement indicated in Burkey's early patent, in which it was proposed that the electric current flow at right angles to the flow of water. With such arrangement the shock received by the fish would be proportional to the thickness rather than the length of the fish.

To accomplish the desired orientation of electric field, McMillan proposed the use of two rows of electrodes with the two rows of opposite polarity. He also recommended large, round electrodes of certain spacing.

In Burkey's second patent, No. 1,292,246, issued in 1919, one of the stated objectives is to arrange the electrodes in such a way as to cause the current to flow lengthwise through the fish, which subsequently was strongly recommended by McMillan. It appears, however, that Burkey was not especially impressed by this feature; in any event, it was not accomplished in any of his early installations. Further, this feature was not represented in Burkey's third patent, No. 1,515,547, issued in 1924. It is of interest to note that on July 12, 1928, in the year of publication of McMillan's report, Burkey applied for a patent (Patent No. 1,882,482) in which this feature of direction of electrical current is an important feature.

During the spring of 1928 McMillan supervised for the power companies a test installation of an electric screen in the tailrace of the Gold Ray power plant on the Rogue River in southern Oregon. The purpose of this screen was to direct the movement of adult salmon that were migrating upstream, that is, to prevent them from entering the tailrace and to cause them to continue up the river. More regarding this screen will appear later.

Shirley Baker and U. B. Gilroy for U. S. Bureau of Fisheries 1928 to 1932

In 1928 the U. S. Bureau of Fisheries received an appropriation of $25,000 specifically for the purpose of studying means of preventing the loss of fish in Federal water diversions. Similar appropriations were received during the following four years. Mr. Shirley Baker was employed to take charge and Mr. U. B. Gilroy did a large part of the work under Baker's general supervision. A great part of this work was devoted to the electric fish screen. (For reports on the work see Baker and Gilroy, 1928, 1930, 1931, 1932, 1933A, 1933B; Higgins, 1930, 1931A, 1931B, 1932, 1933; Gilroy, 1929, 1931; Baker, 1930; Bower, 1931, 1933.)

At the request of Mr. Burkey and through cooperation between the Oregon Game Commission and the U. S. Bureau of Fisheries a demonstration of Burkey's improved electric screen was made at the State's Delph Creek hatchery in September 1928. All who observed this demonstration appeared to be favorably impressed. (See "Observer", 1928; Baker and Gilroy, 1928; and Higgins, 1930).

In order to observe operations under more nearly natural conditions, a test installation was made in October 1928 at the Tieton Canal in the Yakima Valley. Although very few fish were available for the test the screen was considered to be a success and plans immediately were made for its general application in the Federal diversions.

The improved Burkey electric fish screen demonstrated at the Delph Creek hatchery and tested in the Tieton Canal used pulsating direct current. The direct current, in these cases supplied from batteries, was broken into pulsations at a frequency of 6 to 10 per second by an adjustable-pendulum, vibrating contactor which also reversed the polarity of alternate impulses. (See McMillan, 1929). One electrode consisted of a succession of chains spaced a few inches apart and hanging vertically in the water; the other electrode was a pipe or cable along the bottom a few feet upstream from the chains.

In addition to the results of the tests of Burkey's screen, Baker and Gilroy had the published report of the study conducted by McMillan in 1926. They accordingly were confronted with the task of deciding which design to adopt. The two designs differed in that McMillan recommended the use of standard alternating current and large electrodes in two rows, with the two rows of opposite polarity; whereas, Burkey recommended direct-current impulses produced by his so-called "energizer" and an electrode system consisting of a row of closely-spaced, suspended chains or equal as one electrode and a pipe or equal on the ditch bottom as the second electrode.

Soon after the Tieton test, Baker and Gilroy secured the services of McMillan to check the nature of impulses delivered through Burkey's "energizer". As a part of this report McMillan (1929) wrote as follows:

> "The investigation deals only with the electrical characteristics of the Burkey diverter and does not enter into the influence of voltage wave form and frequency on the voltage gradients required to produce paralysis in fish swimming in the electric field produced by such wave forms and frequencies. The writer believes that a very careful and thorough investigation should be made to determine the merits of various wave forms and frequencies for use in electric fish diverters or screens. This proposed investigation should cover the effectiveness of the various wave forms and frequencies and the reliability of the apparatus used for their production."

Baker and Gilroy evidently decided in favor of the Burkey design. In any event, they employed Burkey to construct "energizers" for installation in the following locations in 1929: Wapato Canal, 1800 c.f.s.; Sunnyside Canal 1,500 c.f.s.; Tieton Canal, 320 c.f.s.; and Gold Ray power intake, ±800 c.f.s.

All of these screens were placed at the point of diversion from the river, where the screen was required merely to cause the fish to shear off at an angle in order to continue down the river instead of entering the diversion. The system of electrodes in every case was as described above for the typical Burkey screen. Heavy window weights

on the lower ends of the chains reduced deflection by the current. A typical example is shown in Figure 6, page 1099 of the Bureau of Fisheries publication, "Progress in Biological Inquiry 1929" (Higgins 1931A).

For the Tieton installation a D. C. hydroelectric plant was constructed. For the other three, where power was available, motor generators were provided to convert from A.C. to D.C.

Difficulty immediately was encountered with the pendulum switches, which were not able to carry the heavy current without damage to the contact points. Direct current therefore was abandoned at Wapato and Sunnyside and Burkey's "energizers" were operated with A.C. for the remainder of the season. This reduced but did not entirely eliminate the contact troubles.

Attention is directed especially to the fact that at this time Burkey claimed particular merit for the type of impulses delivered by his "energizer". Stepping ahead a bit in the history of events, it is to be noted that this feature became the principal subject of Burkey's fifth and most important patent (No. 1974,444) for which he made application on June 12, 1929. This feature will become of increasing importance as the history progresses. Burkey described this impulse feature as being characterized by short "on" periods separated by relatively long "off" periods. He claimed two advantages: first, as a result of the current being on for only a small fraction of the time, the power consumption is greatly reduced; and second, the fish has an opportunity to relax its muscles between stimuli.

Recognizing the inherent difficulty of producing such impulses by alternately opening and closing the circuit, McMillan sought other means of accomplishment, and constructed a special saturated-core transformer that produced a sharp-peaked voltage curve. (See accompanying picture of transformer and curve of output voltage.)

In July 1929, Gilroy and McMillan tested this new transformer at the Bureau of Fisheries' Clackamas hatchery. Results accomplished by this special wave form in comparison with the standard sine wave were studied. Of these tests McMillan later wrote: "Results were not conclusive, but indicated that the effective value of the voltage was more important than wave shape."

In 1929 Baker and Gilroy conducted experiments at the Gold Ray power plant, both at the intake screen and in a sluice way. In the latter position various arrangements and spacings of electrodes of both the Burkey and the McMillan design were tried. The voltage also was varied, but evidently the tests were limited to A.C. Mr. Coleman of the Oregon Game Commission assisted throughout the experiments and

McMillan gave some assistance. In referring to these tests in their annual report, Baker and Gilroy (1930) stated that "highly satisfactory results were obtained" with the McMillan design of screen. (See Higgins, 1931 page 1100).

It appears, however, that Baker and Gilroy at the end of 1929 still had difficulty in choosing between the Burkey and McMillan designs. In any event, in 1930 they continued with the Burkey type of electrode system at Sunnyside, Wapato, and Tieton. They also retained pulsating current at these installations but replaced the Burkey "energizer" with a sign-flasher type of interrupter. They made a completely new installation with the Burkey type of electrode system at the Old Indian Canal in Yakima Valley and specified the same design for installation by the Pacific Power and Light Company at their Wapato Canal. These new screens, however, were electrified by direct-connected A.C. Only the Gold Ray intake screen was completely of the McMillan design.

Throughout the season of 1930 Baker and Gilroy gave a great deal of attention to design of the electric screen. They conducted experiments at the Old Indian Canal, the Gold Ray Power plant, and the Fort Klamath hatchery of the Oregon Game Commission. McMillan gave some assistance in the experiments. In their annual report, Baker and Gilroy (1931) (Higgins, 1931B, page 598-9) stated their conclusions as follows:

"These demonstrated: (1) The superiority of the insulated type of screen over the grounded type, (2) the superiority of large diameter electrodes over the chain electrodes as previously employed, (3) the effectiveness of ordinary 60-cycle alternating current without resort to interruption or other modification, and (4) they indicated in general the electrode spacing and screen voltages required for effective operation of the screen."

Although Baker and Gilroy continued to express general satisfaction with the success of their electric screens, basing this impression mainly upon the number of fish observed in the canals when drained in the fall, the following statement in their annual report for 1930 (Baker and Gilroy, 1931), indicates a lessening of confidence in the electric screen: "In the use of the electric screen to prevent small fish, migrating downstream, from entering irrigation and power intakes it appears that this device will never be entirely positive in its action as is the mechanical screen of the type described in the previous chapter."

At the beginning of the season of 1931 all of the electric screens operated by the U. S. Bureau of Fisheries were converted to the McMillan design. (For picture of screen at Wapato Canal see Higgins 1931B, page 596). Even the hydroelectric generator for the

Tieton screen was changed to A.C. It was observed that a good many fish were passing through the screen at the intake to the Gold Ray Power Plant. That screen, accordingly was removed late in May 1931.

A changing attitude of the U. S. Bureau of Fisheries toward the electric fish screen is expressed in the following quotation from its publication "Progress in Biological Inquiries 1931", page 484 (Higgins 1932):

> "Three years of operation with the electric screen has disclosed the weaknesses of this type of fish-protective device. The chief difficulty is in the antagonism which is likely to develop in the public mind when some fish are killed or stunned by contact with the electrified water. Such attitude entirely disregards the fact that the electric screen may be operating to save the majority of fish, but it creates a problem in public relations which cannot be overlooked. Furthermore, the action of the electric screen can never be expected to be 100 percent effective as is the mechanical screen. Another difficulty is the patent situation, which raises a restriction which can be avoided by use of the mechanical screen. For these reasons the investigators do not recommend the electric fish screen for general use. In the case of the electric screens operated on United States Government projects in the Yakima country the situation is somewhat different. There the bureau itself operates the screens, giving them very careful attention and supervision, and in Yakima County, Washington, alone, the use of the electric screen is free from patent royalties. These Yakima screens undoubtedly save a large proportion of the fish, and it is felt that the continued use of these particular electric screens is justified."

Operation of electric fish screens in 1932 was essentially the same as in 1931. The U. S. Bureau of Fisheries then decided to discontinue the use of electric fish screens for the protection of downstream migrants and prepared to install the drum type of mechanical screens. Mr. John Spencer, who formerly had been with the California Division of Fish and Game, was employed to design and supervise construction of such screens in ditches in the Yakima Valley at which electric screens formerly had been operated. When Spencer found that he would not be able to have the mechanical screens in operation for the 1934 season he re-installed the electric screens at the Sunnyside, Tieton, and Old Indian Canals. Those screens were inspected by Holmes and Barnett and found to be in such unsatisfactory condition that they were removed. This ended the history of the operation of electric fish screens by the U. S. Bureau of Fisheries.

USE OF ELECTRIC SCREEN WITH ADULT SALMON MIGRATING UPSTREAM 1928 TO 1932

In Tailrace at Gold Ray Power Plant - 1928 to 1931

Continuing his interest in the electric fish screen, Mr. Yates of the Pacific Power and Light Company, was instrumental in having a test installation made in the tailrace of the Gold Ray power plant on the Rogue River. The purpose of the test was to determine the feasibility of stopping or directing the movement of upstream migrants. In this instance the screen was designed to prevent the fish from entering the tailrace and to direct them to continue on up the river.

The first installation, made in the spring of 1928, was in accordance with the McMillan design. That is, it was connected directly to an ungrounded A.C. power source, and the electrodes were in two rows, insulated from ground. The electrodes were one-inch in diameter, however, rather than of larger size as recommended by McMillan.

Soon after the screen was installed sportsmen fishing in the river below it reported seeing dead fish that presumably had been killed by the screen. Following the sportsmen's protests, the power company turned the power off until an inspection could be made. Without a very satisfactory conclusion as to whether the electricity had killed fish, the power was turned on again and the screen operated for the remainder of the season without significant complaint.

Beginning with the season of 1929 this screen was operated in cooperation between the power companies and the U. S. Bureau of Fisheries, with Baker and Gilroy in charge of operations. In 1929 the special McMillan transformer described on page 8 was used as a source of power, and the electrode system was changed to the Burkey design of chains and ground. This screen was reported to have functioned quite satisfactorily.

In 1930 the screen was changed several times. Finally in July the McMillan design of electrodes was installed, with two rows of 6-inch diameter pipes insulated from ground. The season's operation again was reported as successful.

Operation of the screen was resumed in 1931. In April of that year sportsmen reported many dead fish in the river below the power plant and insisted that the screen be shut off. It was reported that many of the fish had their backs broken, presumably as a result of the electric shock.

In the course of the investigation of the situation it was learned that at about the time the large number of dead fish was observed there had been a failure in the power company's transmission lines, which caused a high-voltage circuit to become shorted through the river. McMillan, Baker, and Gilroy all became convinced that the killing of fish was due to the power failure and not either directly or indirectly to the fish screen. These men also were convinced of the merit of the electric screen in keeping the fish out of the tailrace, but the sportsmen insisted that the screen be permanently removed.

This experience with the sportsmen of Rogue River Valley had a great deal to do with causing the U. S. Bureau of Fisheries to withhold approval of general use of the electric screen. (See comments on page 10.)

For further comment on the subject of injury by alternating current see pages 17 and 43.

Counting Weir Kvichak River, Alaska - 1930 and 1932.

As a part of a biological study of the salmon runs in Alaska streams, the U. S. Bureau of Fisheries counted the numbers of adult salmon going up some of the streams to spawn. After difficulty had been experienced in an effort to place a webbing barrier across the Kvichak River for counting the fish, the electric screen was tried.

The first trial was made in 1930. The installation consisted of picket fences extending 270 feet out from one shore and 80 feet out from the other, and an electrified area extending 780 feet across the deeper, center portion of the river. The electrode system was the Burkey design consisting of suspended chains, and a pipe laid in contact with the bed of the stream. The electrification was continuously applied A. C. This screen was successful in stopping the fish but the fish failed to pass through the counting gates provided in the picket-fence sections, so it became necessary to shut off the electricity in order to permit the fish to pass. (See Baker and Gilroy, 1931; Higgins 1931B, page 599, and Bower 1931, pages 32-33.)

In 1932 the use of an electric screen again was tried on the Kvichak River. In this case a new site was selected where two parallel islands divided the river into three channels. Picket fences with counting gates were constructed across the upper ends of the two outside channels and the electric screen placed across the main channel between the islands. The electrode system was a modification of the Burkey design, from which it differed only in that the pipe electrode, instead of resting on the bed of the stream, was supported at a distance of approximately a foot above the bottom. The electricity, as before, was A. C.

This screen was reported to be thoroughly successful (See Baker and Gilroy 1933A; Higgins 1933, pp. 112-113, and Bower 1933, pages 27-28.) More than 5 million salmon were counted through the gates; none was observed to pass through the screen; and less than 200 were found to have been killed by the electric current.

Plans to operate this screen in 1933 were abandoned due to a shortage of funds.

Green River Test - 1930

In 1930 the U. S. Bureau of Fisheries in cooperation with the Northwest Electric Light and Power Association and the Washington Department of Fisheries, installed an experimental electric fish screen on the Green River, near Auburn, Washington. The objectives of the tests were to determine the feasibility of using the electric screen (1) to block the passage of fish preparatory to catching them for artificial propagation, (2) to direct fish to the entrance to a fishway, and (3) to divert fish from a main stream into a tributary.

The screen was the McMillan design, electrified by A.C., and had 6-inch, round electrodes in two rows, insulated from ground. It was placed so as to block the main Green River just above the mouth of Soos Creek. The screen was reported to be successful in all respects except that after finding their passage in Green River blocked the fish did not go up Soos Creek. This, however, was not the fault of the screen.

For further reference to use of electric screen with adult salmon see sections of this report entitled "Effect of Alternating Current upon Adult Fish" and "Experiments at Mill Creek, California, with Adult Salmon Migrating Upstream - 1942".

FURTHER RESEARCH - 1934 TO 1937

Study of Potential Gradients by McMillan and Barnett 1934 and 1935

In 1934, soon after being assigned by the U. S. Bureau of Fisheries to the task of assisting with the design of fishways for Bonneville Dam, Mr. Harlan B. Holmes consulted Prof. McMillan regarding the advisability of considering the electric fish screen for Bonneville Dam, and the need of further research. McMillan recommended further research relating to the distribution of electrical potential gradient in the water with various electrode arrangements.

Holmes arranged for the employment of McMillan on a part-time basis to supervise a study, and for the full-time employment of Mr. H. G. Barnett, a graduate electrical engineer.

The first task was to design and construct a special volt meter for measuring the potential gradient in the water. This became necessary because an ordinary volt meter draws significant current from the circuit in which the measurement is being made. To draw such current from the water in which the voltage is being measured would so distort the field as to give an incorrect reading.

The meter designed and constructed by McMillan and Barnett is described and illustrated in an unpublished report entitled "A Vacuum Tube Crest Voltmeter. Description and Instructions", by Glen Barnett, dated March 1936. The meter was completed nearly two years before the date of the report. In fact, Barnett and Holmes used it in June 1934 to test the electric fields at the electric screens in the Yakima valley. (See comment on page 10.)

After completing the volt meter, McMillan and Barnett proceeded with the study of potential gradients in the water. For this study a concrete-lined swimming tank in one of the buildings at Oregon State College was secured.

Using single-phase alternating current, the distribution of potential gradients in the water field was determined. The greater part of this work was done with variations of the electrode arrangement that has been referred to above as the McMillan design; that is, it involved 6-inch-diameter electrodes, in two rows, and with current flowing from one row to the other. The work was extended to include grounded circuits but not exactly the closely-spaced, suspended electrodes and a small ground electrode that has been referred to above as the Burkey design. A preliminary report on this part of the work was presented in an unpublished report entitled "Preliminary Report on U. S. Bureau of Fisheries Electric Fish Screen Investigation at Oregon State College" by McMillan and Barnett (1935).

The study of the distribution of voltage gradients in the water was continued with three-phase alternating current. It was hoped that these would create complex, continuously-changing fields in the water that would make it impossible for a fish to take any position in the electric field that would remain continuously at minimum voltage gradient. Due to a shortage of funds it became necessary to drop this work before a final report was prepared, but the data are available and essentially the same results were obtained in field tests which are described later in this report.

Field Tests by Holmes and Morton in Table Rock Ditch - 1936

During the summer of 1936 Holmes, assisted by Mr. Frederick G. Morton, conducted field tests on the Table Rock irrigation ditch which takes water from Rogue River near Central Point, Oregon. This site was selected in order to obtain naturally-migrating salmon fingerlings and to have the advantage of a drum-type fish screen as a means of checking the extent to which fish passed through the electric screen.

The electric screen was installed in the ditch about 200 feet upstream from the drum screen. A by-pass was cut through the bank to permit fish diverted by the electric screen to return to the river. A trap constructed in this by-pass permitted checking the number of fish diverted. A similar trap was constructed in the by-pass at the drum screen.

By the use of the McMillan-Barnett vacuum-tube volt meter, the distribution of voltage gradients with various electrode arrangements was measured. For each arrangement the response of the fish was determined by direct observation and by the catches in the two by-pass traps.

The electrode arrangements tested included both the Burkey and the McMillan designs. None was found that could be considered even moderately successful in diverting the fish to the by-pass that carried approximately one-tenth as much water as passed through the screen and continued down the ditch. Although the fish responded definitely to the electrical stimulus and usually were temporarily stopped by it, it appeared that their determination to migrate downstream was much greater than their fear of the electrical stimulus, and they soon either drifted or swam so far into the electric field that they lost control of their muscles and the flowing water carried them through the electrified area.

Field Tests by McMillan and Everest on Table Rock Ditch - 1937

Holmes was aware of the fact that, although he had a fair knowledge of electricity, someone with greater background in that field might have succeeded where he failed to accomplish successful field tests with the electric screen. He, therefore, welcomed the suggestion of the Northwest Electric Light and Power Association that they obtain the services of McMillan to conduct further field tests. The field station on the Table Rock Ditch was made available and McMillan, assisted by Prof. Alton Everest, conducted tests during the summer of 1937.

These tests included both single- and three-phase alternating current. The results were presented in an unpublished report by McMillan and Everest (1937A).

McMillan and Everest confirmed the findings of Holmes, in that they were unable to accomplish the desired results with normally migrating fingerlings. The final attitude of these investigations is best indicated by the following quotation from their report:

> "Observations of the behavior of fish in both the single-phase and three-phase, 60-cycle electric fields showed quite conclusively that if the voltage gradients were maintained sufficiently high to be uncomfortable to the fish a distance of from three to four feet above the screen, the gradient would be so high near the electrodes that the fish entering the electrified area swiftly or with an apparent determination to pass through would enter the field so far they would be completely paralyzed before the pain of the electric shock would be sufficient to cause them to turn back. In this completely paralyzed condition, the fish are either carried through the screen by the flow of the water, in which case they frequently recover, or if the water is sluggish they settle to the bottom and die in the electric field. In addition to the ineffectiveness of the 60-cycle, single- and three-phase fields in turning back fish that enter there, there is another effect of excessive muscular contraction induced by continuously applied 60-cycle voltages that may tear muscle tissue and even crush the vertebrae when fish are suddenly subjected to excessive voltage gradients.
>
> "The experience with 60-cycle, alternating current fish screens at Bonneville, Oregon, in 1926 reported in the U. S. Bureau of Fisheries Document No. 1042 and the Bulletin of the Bureau of Fisheries, Volume XLIV, 1928, where an electric screen was successfully used with salmon fingerlings in a hatchery pool, appears to be at variance with these observations. This apparent discrepancy is probably due to the fact that fish are rather quickly trained to avoid an electrified area; hence, migratory fish entering an electrified area for the first time behave in an altogether different manner than fish held in a pond where an electric screen is installed. It was in anticipation of the possibility of such a discrepancy between hatchery experiments and stream experiments that the recommendation was made in the 1928 report that 'Actual stream installations be made, carefully observed and developed'.
>
> "As a result of the observations with 60-cycle screens, it is concluded that there is very little possibility that such screens can be successfully used against downstream migratory fish."

Effect of Alternating Current upon Adult Fish

It will be recalled from an earlier section (page 12) of this report that there were reports of the killing of fish by the electric screen in the tailrace of the Gold Ray power plant. McMillan, Baker, and Gilroy concluded that although electricity from the shorting of a power line through the water may have killed fish, the electric screen certainly had not killed any significant number. This conclusion was strengthened by the experience on the Kvichak River in Alaska and at the experimental screen on the Green River.

The reports of fish killed in the Rogue River included statements to the effect that in many cases the backs of the fish were broken. This seemed impossible.

Incidental to the field tests conducted by Holmes and Morton in 1936, a number of adult salmon, steelhead trout, suckers, and other fish drifted down the ditch and encountered the electric field. As the potential gradients were maintained high enough to affect the fingerlings, the much larger adult fish received especially severe shocks and many of them were killed. To the great surprise of the observer, it was found that most of the fish that were killed had conspicuously damaged tissues. In many cases the backs were broken, in others several ribs were torn away from the vertebrae, and in one instance of a large salmon, the muscles on one side of the fish were pulled apart to the extent that the injury could be seen distinctly as a depression in the skin. Some fish with such serious injuries remained alive for several days.

Upon further consideration of muscular contraction by electrical stimulation, these injuries did not appear surprising. It is well known to physiologists that 60-cycle alternating current is a very effective stimulus that will cause violent and sustained contraction of muscles. Such a succession of electrical stimuli of only moderate strength will cause muscle contraction far greater than can be caused by a single stimulus regardless of its strength. Stronger A.C. stimuli are able to produce contractions much greater than ever result from normal voluntary stimulation. Instances of breaking bones, even in humans, as a result of alternating current shock are not uncommon. For example, in the use of shock in the treatment of psychiatric disorders a significant proportion of patients suffer fractures of long bones and compression fractures of vertebrae (Bennett, A. E., 1946).

After considering the physiology of muscle contraction resulting from stimulation by alternating current, the surprising thing is that salmon fingerlings do not suffer injury to tissues such as the breaking of their backs. No thorough study has been made to assure that such injuries do not occur, but upon the basis of general experience

and casual observation it does not appear that they occur. The difference in response of young and adult fish may be due to difference in the strength of the muscles or flexibility of the bones or a combination of the two.

BURKEY'S IMPULSE GENERATOR - 1936 TO DATE

History and Principle

It is to be recalled that as early as in 1928 Burkey recommended the use of voltage impulses, and that in 1929 he applied for a patent on this feature (Patent No. 1,974,444, issued 9/25/43). In the screens designed by Burkey in 1928 and 1929 the voltage impulses were obtained by interrupting direct current by a mechanical contactor.

At some time prior to 1936 Burkey secured the assistance of the General Electric Company, with the result that employees of that company developed an electronic circuit by which it is possible, using A.C. as a source of supply, to deliver single half-wave impulses at a selected frequency. This circuit is covered by patent No. 2,016,147, issued on October 1, 1935. Burkey may have sold several of these half-wave-impulse outfits in different parts of the country, but the only one of which record is available is one that was sold in 1936 to the California Division of Fish and Game for installation on the Granada ditch. Tests of this screen are discussed in a later section of this report.

At the time the Granada installation was being tested, Burkey was developing another impulse generator that utilized the cyclic charging of an electric condenser and then discharging it through the water. Toward the end of the Granada test Burkey substituted a generator of this type in the place of the energizer originally sold to the State. This initial outfit utilized a rotary switch for controlling the frequency of discharging the condenser through the water.

A little later Burkey developed an electronic circuit for charging the condenser to a selected voltage and discharging it at a selected frequency. This circuit was described in an article by F. L. Reinmann (1946). It is understood that the energizer now manufactured for Burkey by Westinghouse is a slight modification of this circuit.

Study of response of fish to impulse voltages by McMillan, Everest, and Holmes - 1936 and 1937

After learning of Burkey's new feature of employing condenser discharge for electrifying a fish screen, Holmes conducted some preliminary experiments at his Table Rock field station in 1936.

The next year, after becoming convinced that alternating current probably never would be satisfactory for a fish screen, McMillan and Everest took up the study of the use of condenser discharge. They first designed and constructed an impulse generator, which they described in an unpublished report entitled "The Design of an Impulse Generator for Electric Fish Screen Research" (McMillan and Everest, 1937). Using this generator, McMillan, Everest, and Holmes (1937) conducted experiments with salmon fingerlings and described their findings in an unpublished report entitled "The Response of Fish to Impulse Voltages."

That report first presents some of the fundamentals of the response of muscles to a single electrical stimulus, including the definition, significance, and measurement of chronaxie. It then describes experiments that were conducted to determine the fundamentals of the response of salmon fingerlings to single stimuli from the discharge of a condenser. The relation is established between the response of the fish and the three electrical variables: (1) voltage to which the condenser is charged, (2) capacitance of the condenser, and (3) the resistance of the circuit (the water) through which the condenser is discharged. It further is shown that the response of the fish is greater when facing the negative electrode than when facing the positive electrode. The effect of frequency of shock is discussed.

PROPOSAL TO TEST BURKEY SCREEN IN CALIFORNIA - 1936

In this history of the electric fish screen the last previous reference to Mr. Burkey's activities with the electric fish screen was his design and construction of screens for canals in the Yakima Valley during the spring of 1929. Immediately following that time Burkey was seriously ill, but when he regained his health he renewed his typical vigor in promoting the electric screen. Details of his activities for the next few years are not known to the writer. It is known, however, that he had made certain improvements and that he made a great effort to have his improved screen adopted by the California Division of Fish and Game.

By 1936 Burkey had gained enough support in California to induce the State to consider giving his screen another trial. Mr. John Spencer, who had returned to the California Division of Fish and Game after constructing screens for the U. S. Bureau of Fisheries, endeavored to secure the financial cooperation of the U. S. Bureau of

Fisheries in a test of the Burkey screen. In the course of correspondence on this subject, Holmes wrote as follows (Holmes to Spencer, January 24, 1936):

> "Before considering financial cooperation in a field test of the nature proposed, we should find it necessary to have more information. We should require a description of the device, that is, the nature and arrangement of electrodes to be placed in the water; the characteristics of the current applied; such as potential, direct or alternating, constant or pulsating, frequency, etc. We also should like to know exactly what features are considered to be covered by Mr. Burkey's patents".

In reply to this inquiry Spencer (Letter of February 4, 1936 to Holmes) wrote in part:

> ". . . I have written Mr. Burkey and he advises that it is impossible for him to answer all of the questions because some of them are 'trade secrets'. . . He claims there are several patented circuits embodied in his electronic impulse control type B, which is sold under General Electric license agreement, and hence he cannot divulge characteristics of the wave form generated by the device. . ."

On February 7, 1936 Holmes replied to Spencer as follows:

> "I am unable to understand the attitude of Mr. Burkey toward furnishing the information requested in my letter of January 24. He certainly could not expect any Government department to finance the demonstration of some mysteriously secret device, nor could he expect such a department to place its stamp of approval upon a device without knowing what that device is. Further, if Mr. Burkey's electric screen depends for its success upon his personal contact in especially adapting the device to the specific conditions of each individual installation, I am unable to understand what is to be gained by one demonstration. I could not approve the expenditure of Government funds for an installation unless it would give promise of demonstrating the merit of features that could be generally applied.
>
> "If Mr. Burkey's only opportunity for financial gain in connection with the electric screen was the sale of his so-called 'trade secrets', I should be better able to understand his attitude. This, however, is not the case, as Mr. Burkey holds five patents relating to the electric screen. If features of the electric screen developed by Mr. Burkey have merit, he should anticipate royalties on the basis of his patents.

"I am especially disappointed in Mr. Burkey's attitude because I believe there may be merit in his patented features and I should like to see them adequately investigated with an attitude of giving to Mr. Burkey full credit for his accomplishments. I could not, however, recommend the expenditure of Government funds without more knowledge as to what is proposed to be installed. In fact, I know of no way in which the Bureau of Fisheries could purchase a device without specifications. Let us hope that Mr. Burkey will see fit to furnish the information requested or will offer more convincing explanations for his failure to do so."

The information requested was not furnished and nothing more was done about the proposal of a cooperative test. Most of the information requested by Holmes later was received. A record of the General Electric patents was secured directly from that company. Other information was obtained directly from Burkey with the understanding that it was to be treated as confidential. This information since has become available through other channels and can be revealed. Comment regarding it is presented in a later section.

This instance has been presented in detail because it indicates the consistent attitude of Burkey, which it is believed has greatly retarded Burkey's own progress in developing the electric screen.

FIELD TEST OF BURKEY SCREEN AT GRANADA, CALIFORNIA - 1936

The proposed field test referred to above was conducted by the California Division of Fish and Game without the financial cooperation of the U. S. Bureau of Fisheries. The site selected was the Granada ditch which takes water from the Shasta River near Yreka, California.

It is understood that in so far as Burkey was concerned this was not an experiment but merely a demonstration of an electric screen that he claimed to be a perfected product and that he delivered in place as an outright sale to the State. The State then conducted a test to determine the efficiency of the screen.

The screen was installed a hundred feet or more below the headgates of the ditch (Pictures of this installation appear in Electronics Digest No. 2 and in an article by J. O. Case (1938) page 33 and upper left on page 32). Advantage was taken of an abandoned concrete section of ditch where a drum screen formerly had been installed. Just upstream from the electric screen a by-pass back to the river was provided. The electrode system was typical of that previously described as the Burkey design. One electrode consisted of a row of closely-spaced, round, brass rods suspended from a cable above the water. The other electrode was a wire extending across the ditch bottom a few

feet upstream from the hanging electrode. The exact nature of the impulses delivered to the water by the so-called "energizer" was not revealed at the time of purchase. Further comment regarding it is made in the following section.

In making its tests of the screen, the State constructed a trap in the by-pass to determine the number of fingerlings diverted, and operated a fyke (trap) net in the ditch below the screen to check the number that passed through the screen.

Despite the fact that the U. S. Bureau of Fisheries did not see fit to formally take part in the test, Holmes was invited to make observations, which he did on several occasions. (At the time of one of these visits Holmes and Burkey met for the first time.) Holmes assisted Burkey in every way possible in an effort to make the screen a success.

No formal report of the State's findings has been received, but from direct observation and other information it is known that the screen was considered to be a failure and was removed by the State.

ACTIVITIES OF FISHTITE ELECTRIC SCREEN COMPANY
1937 to 1939

Sometime during the winter of 1936-1937 Holmes and McMillan were called upon by Mr. Franklin S. Bonner of Kootenai, Idaho, who stated that he and associates had acquired or were considering acquiring the exclusive rights to market Burkey's electric fish screen in the Northwest States. He requested advice as to how he might get approval of installations. Both Holmes and McMillan independently advised Bonner that the electric screen was in the experimental stage and that they could not recommend its application at that time. They accordingly advised that Bonner give up consideration of marketing the screen. Upon failing to convince Bonner of the merit of this advice, McMillan and Holmes recommended that Bonner and his associates first become familiar with the electric screen by conducting a field test. Holmes, in fact, offered to aid in such a test by securing a site and giving advice. Holmes further secured from the Oregon Game Commission the commitment that, if and when Bonner became convinced by experience that he could install a successful electric screen, the Game Commission would aid in securing a customer for an initial installation and at their own expense would check its efficiency. Bonner decided to accept this advice and offer of assistance.

A company known as the "Fishtite Electric Screen Company" was formed. Associated with Mr. Bonner in this company were Mr. P. L. Savage and Mr. G. F. Maughmer. Although Mr. Bonner had no previous

experience with electricity, his two partners were well qualified electrical engineers, employed by General Electric Company in Los Angeles, California; in fact, both men still hold responsible positions with the same office.

The site selected for the Fishtite Company's trial was the Gold Hill ditch which diverts from Rogue River near the town of Gold Hill, Oregon. Tests at this site were conducted during the summer of 1937.

The arrangement of electric screen, drum screen for checking, and by-passes was essentially as described above for the Table Rock field station. As commercial power was not available, a portable gasoline-engine-powered generator was provided. The electrification was by a Burkey condenser-discharge unit, and the electrode system also was the Burkey design. The experiments and accomplishments are described in a mimeographed report entitled "The Electric Fish Screen as tested on the Gold Hill Irrigation Canal, Gold Hill, Oregon, Summer 1937" (Fishtite Electric Screen Co., 1938).

The experimenters found it necessary to change the voltage output of their energizer first from 500 volts to 900 volts and finally to 1660 volts. The success measured in terms of the proportion of fish by-passed above the electric screen was increased from 36 percent at 500 to 48 percent at 900 volts and to 70 percent at 1660 volts. Limitations of time and equipment prevented the use of still higher voltage at which the experimenters believed that they could have attained at least 85 percent, which was the value set by the Oregon Game Commission for acceptance. The conclusion stated in the report of the test is as follows:

> "1. The electric fish screen will divert or stop fingerling salmon in downstream migration when applied with a sufficiently high voltage under conditions as outlined by this report.
>
> "2. The difficulty of stopping or diverting fingerling salmon in downstream migration can be materially reduced by providing a by-pass scientifically designed to provide the most acceptable conditions for the fish.
>
> "3. Neither fingerling or large salmon are injured by the condenser discharge type of impulse generator as tested and reported here."

During the winter of 1937-38 the Fishtite Electric Screen Company conducted laboratory tests in Los Angeles. In addition to experimenting with condenser discharge, they tried other methods of producing electrical impulses.

During the summer of 1938 this company took advantage of the availability of the field station on the Table Rock ditch where commercial power was available. Although Holmes visited the field station while the experiments were in progress and otherwise was familiar with the work he does not have complete knowledge of the work and no report of the accomplishments is available. The important conclusion from the work is that, despite the encouraging results during the preceding summer, the Fishtite Electric Screen Company decided that their results were not satisfactory. This conclusion is confirmed in a letter of February 11, 1948 to Holmes, in which Savage stated: "We convinced ourselves, at least, that the electric fish screen was not the answer as far as migratory fish were concerned . . . "

The company gave up its contract with Burkey and was dissolved.

DEMONSTRATION AT MT. SHASTA HATCHERY, CALIFORNIA - 1941

In May 1941 Mr. Burkey and his partner Mr. Bert L. Laing conducted a demonstration of their electric screen for the California Division of Fish and Game at the Mt. Shasta Hatchery. The general plan of the demonstration was to place the electric screen across a pond 50 feet long, midway between the two ends. A quantity of fish then was placed in the upstream end of the pond and after a selected interval of time the fish that had passed through the screen to the downstream half were taken out and counted. The fish used were king (chinook) salmon averaging 1½ inches in length and rainbow trout 8½ inches long.

The results are presented in a report prepared by representatives of the California Division of Fish and Game (1941) entitled "Electric Fish Screen Demonstration Conducted for the California Division of Fish and Game by the Electric Fish Screen Company at Mt. Shasta, California". The conclusions stated in that report are as follows:

> "1. In currents of any considerable velocity the Electric Screen would be ineffective in preventing the passage of small fish less than two inches in length. Fish of this size constitute a very large portion of the migratory fish that need protection at diversions.
>
> "2. The Electric Screen is increasingly effective as the size of the fish increases, provided there is no strong impetus to move through the electrified zone. Its effect on 1 or 2 year old steelhead during downstream migration could only be determined by further tests.

"3. In the second series of tests on king salmon where the fish were fed below the screen, it appears that the added stimulus caused fish to move through the screen. It might, therefore, be expected that more difficulty would be experienced in stopping fish where movements were actuated by a strong stimulus.

"4. The most promising field of possible usefulness for the electric screen would appear to be in waters where the fish are non-migratory in habit and where the primary objective is to prevent the passage of adult fish. In the central valleys such conditions obtain and data should be gathered on the effectiveness of the unit now installed at Lake Yosemite by the Modesto sportsmen.

"5. In the development of the Electric Fish Screen a great deal of time has been given to the mechanical and electrical problems involved but relatively little work has been done on adapting or testing the equipment for use under field conditions. During the present tests the operators stated that they had never tried the screen on salmon of such small size. Since the protection of fish of this size and type is one of the principal fisheries problems in diversions on the Pacific Coast, it is evident that they have not had the time nor the facilities to obtain data which would make it possible for them to be assured of the effectiveness of the equipment. The full development and testing of the equipment would require considerable in time, money and facilities. If the owners of the electric fish screen are not in a position to carry on this additional work, other agencies interested in fish conservation might find it desirable to do so, but this added expense could only be justified if there was some definite understanding as to the conditions under which use of the device would be permitted by the owners. The amount necessary for future work might easily exceed that which has already been expended on the mechanical work and there is also a possibility that the device would even then have only a limited usefulness."

Mr. Burkey has stated that he does not consider the report to be a fair presentation of the facts. The conclusions quoted above, in addition to summarizing the results of the tests, obviously are extended to include the views of the author of that report.

CHECK OF EFFICIENCY OF ELECTRIC SCREEN AT LAKE YOSEMITE, CALIFORNIA - 1941

In 1940 the Merced County Fish and Game Protective Association purchased one of Burkey's screens and had it installed in one of the outlets of Lake Yosemite. The purpose of the screen is to prevent the loss of spiny rayed, resident fish into the outlet which is an irrigation canal.

In July 1941 Messrs. S. Ross Hatton and G. H. Clark, Biologists, employed by the California Division of Fish and Game endeavored to check the efficiency of the screen by operating fyke nets above and below the screen. Their work is described in an unpublished report dated August 20, 1941, entitled "Tests of the Electric Fish Screen at Lake Yosemite" (Hatton and Clark, 1941).

The tests were limited to four days during which time only 5 fish were caught above the screen and the same number were caught below the screen. Considering the small number of fish caught and the fact that those caught below the screen may have been part of a resident population in the canal, the observers did not consider their results to be conclusive.

The sportsmen who purchased the screen have been well pleased with its operation, as is indicated by the fact that after two years of operation of the first screen, the Association purchased another screen for the second outlet of the lake.

EXPERIMENTS AT MILL CREEK, CALIFORNIA, WITH ADULT SALMON MIGRATING UPSTREAM - 1942

In connection with the protection of salmon as a result of the construction of Shasta and Keswick Dams on the Sacramento River near Reading, California, it appeared that it might become desirable to use an electric fish screen to block the passage of fish at Keswick Dam. Previous experience reviewed above had indicated that alternating current should not be used because of the danger of injuring fish (See section of this report entitled "Effect of Alternating Current upon Adult Fish"). Upon the basis of theoretical consideration and minor experience it appeared that impulse voltages such as those delivered by Burkey's latest "energizer" would not injure the fish. It was not known, however, whether the Burkey screen would prevent passage of the fish.

Arrangements, therefore, were made between the U. S. Fish and Wildlife Service and Mr. Burkey for a cooperative test. Mr. Burkey and his partner, Mr. Laing, agreed to furnish the energizer, their own services, and pay their own expenses. The Fish and Wildlife Service furnished all other equipment and facilities, and the services of Mr. Holmes and his assistant, Mr. Clifford J. Burner. The Fish and Wildlife Service hatchery on Mill Creek, a tributary of the Sacramento near Los Molinos, California, was selected for the tests. The tests were conducted during October and November, 1942.

The original plan of the experiment was to test the ability to shunt the fish away from a minor side of the channel while permitting their passage up the major portion, and vice versa, also to test the more difficult task of completely blocking the passage of the fish for a period of several days. A number of complicating circumstances made it necessary to alter this plan. Among these conditions was a shortage of water in the creek which delayed the fish, a predominance of small (jack) salmon that could move freely back and forth through the hatchery rack (picketed barrier across stream), prevailing fish activity at night instead of during the daytime as anticipated, and finally limitations in the power output of the electrical equipment furnished by Burkey.

The work became primarily a study of the electrical features. Holmes designed and constructed a vacuum-tube voltmeter for measuring the crest values of the condenser impulses, and a stroboscope for checking the frequency of impulses. He also utilized the McMillan-Barnett meter for plotting the distribution of voltage gradients in the water with various minor changes in the electrode system. Much time was devoted to discussion of the electrical characteristics. Through these discussions Holmes endeavored to pass along to Burkey the results of his previous experience, especially that obtained with McMillan and Everest on the response of fish to impulse voltages.

As the experiments progressed the electrical characteristics were changed many times in an effort to accomplish maximum efficiency. The voltage was progressively increased to the capacity of the equipment available, which was approximately 1,000 volts. The capacitance of the condensers was either 90 or 120 microfarads. The electrode system was divided near the middle of the channel; one side had a resistance of 19 to 27 ohms; the other, from 22 to 31 ohms; and the two together, from 11 to 15 ohms. The frequency of impulses was varied between 6 and 10 impulses per second. Higher frequencies were not used because of the danger of injury to the fish. No formal report of the test has been prepared but additional electrical data are available.

The most extensive observations with respect to the action of fish were conducted at night with the aid of flood lights. Observers stood on a bridge just upstream from the electrodes and recorded the activity of the fish. That is, they recorded for each fish the maximum distance that the fish progressed upstream. The fish normally remained in a deep pool a little below the lighted area. When a fish came out of the hole it normally would make one trial at the electric screen. Unless it got through the screen it returned to the deep hole. This type of activity made it possible for the observers to watch each fish and record its accomplishment. As it was not possible to recognize each individual fish it usually was not possible to determine how many trials were made by each fish. Therefore, the records were in terms of "fish trials" rather than the final accomplishment of individual fish. The results varied greatly as the electrical characteristics were altered in an effort to accomplish the most efficient screen. The maximum success attained was the turning back of approximately 80 percent of the "fish trials" while the remaining 20 percent went through the screen.

Holmes and Burkey were not able to agree on the interpretation of these results. Burkey concluded that if 80 percent of the fish trials resulted in the fish being turned back the efficiency of the screen was 80 percent. Holmes felt that the number of trials that an individual fish might make should be taken into consideration. For example, if in 20 percent of the fish trials the fish went through the screen and continued on upstream, it would be necessary, on an average, for each fish to make only 5 trials in order that all of the fish eventually would get through. It is probable that most fish would make many times 5 trials before giving up. Holmes, therefore, did not consider the screen to be successful in stopping the fish.

In the course of the tests with the fish in the stream a number of fish were "knocked out" to the extent of becoming unable to swim. The slang term "knocked out" is used because it is not known just what happened physiologically. When the fish were removed from the electric field, for example, by drifting downstream, they were observed to recover equilibrium within a few seconds.

To obtain more exact data regarding the effect of severe shock by impulse voltage, a large salmon was placed in a live crate and given a severe shock for 10 seconds. During this time the fish thrashed about violently but did not lose equilibrium. It later was killed and dissected and no injury to tissues was found. The following characteristics define the shock to which the fish was subjected: initial potential of each impulse as applied to the fish, approximately 400 volts; time factor of each impulse 2 microseconds (R - 18 ohms, C = 120 mfd.);

frequency 7.8 impulses per second. For the significance of these values see McMillan, Everest and Holmes (1937).

A number of fish that were killed also were dissected; none was found to have injuries such as those previously observed as a result of shock by alternating current.

SIERRA PACIFIC POWER COMPANY'S TRUCKEE RIVER SCREEN - 1942

In August 1942 the Sierra Pacific Power Company removed an old bar-type of fish screen and installed a Burkey screen in the intake to its power plant on the Truckee River near Floriston, California. The screen is described and illustrated in an article entitled "Electrical Fish Screen Saves Steel", by Mr. T. J. Welsh, Assistant Engineer, for the power company, which was published in Electrical West, January 1943, pages 37 and 38.

It seems surprising that the California Division of Fish and Game would have approved such an installation when a little more than a year before, upon the basis of tests at their Shasta Hatchery, they had not found the electric screen satisfactory for such an installation. It is believed that no new data became available to them during the intervening period.

An article in the March 8, 1946 issue of the "Evening Gazette" published in Reno, Nevada, indicated that the sportsmen of that area were very favorably impressed by the success of this screen and that plans were being made for general adoption of Burkey's screen in the Truckee Valley. Several verbal reports of the same nature also have been received.

Although Holmes has no first-hand facts regarding the success of this particular screen, analysis of the available evidence does not seem to justify the attitude taken. It is understood that the screen is located at a considerable distance from the headgates, that there is no by-pass at the screen to permit the escape of fish stopped by the screen, and that the water velocity at and above the screen is rather high. Evidently judgment of the success of the screen is based primarily upon the observation on one or more occasions when the canal has been drained, that there were only a few fish in the section of the canal below the screen. Upon the basis of past experience with both mechanical and electrical screens, plus the fact that any fish that may have passed through the electric screen during the several months prior to draining the canal may have continued downstream and through the power plant, it is believed that the absence of fish in the drained canal is not reliable evidence of success of the screen. A similar attitude recently

was expressed by an official of the California Division of Fish and Game who wrote: "The screen on the Truckee River was installed by the power company at their own volition and we had very little to say about it. It is unsatisfactory in that it is located well down the canal, velocities are entirely too high and there is no by-pass. Under the circumstances we have not felt it even worth while to attempt a check."

HAT CREEK ELECTRIC SCREEN EXPERIMENTS - 1943, AND PIT 5 INSTALLATIONS

The Pacific Gas and Electric Company was confronted with a problem of fish protection in connection with their plans for a new power project known as "Pit 5", on the Pit River in Northern California. This company wished to consider the electric screen. As the State was unable to approve such a screen without evidence of its success, it was decided that an electric screen should be installed at the company's Hat Creek plant No. 2, and that success of that screen would serve as a basis of approval of a screen for Pit 5.

A screen for the Hat 2 plant was purchased from Mr. Burkey and was installed in June 1943. Mr. J. H. Wales, District Fishery Biologist for the California Division of Fish and Game, then made a study of the efficiency of the screen. The results of the test are presented in a report by the California Division of Fish and Game entitled "Summary Report of Electric Fish Screen Tests at Hat 2 Power House Intake, June and July, 1943."

Holmes visited the site of the screen with Burkey and Laing in November 1941. He later inspected the electrode system before the water was turned in. During the course of Wales' tests Holmes again visited the screen and with the aid of the McMillan-Barnett meter assisted Wales in studying the distribution of voltage gradients in the water.

For location of the Hat 2 screen Burkey took advantage of a new, reenforced concrete intake structure. He used the trash racks as one electrode and a very coarse, insulated grillage of 1½-inch pipe was provided on the downstream side of the trash racks as the other electrode. Holmes endeavored without success to convince Burkey of the fact that this proposed electrode arrangement could not produce an electric field in the desired area upstream from the trash racks. This fact immediately was demonstrated when the screen was electrified. The downstream electrode then was abandoned and a system of insulated pipe electrodes was placed three feet upstream from the trash racks.

Mr. Wales found that the water velocity in the canal below the screen was too swift to permit the use of fyke nets or other means by which it would be possible to determine how many fish passed through the screen. He therefore resorted to the use of an open-ended live crate in which he placed fish and determined the relative efficiency of different electrical arrangements in keeping the fish from leaving the crate by way of the open end. By varying the position of the crate, he also determined the effective strength of the electric field at various distances from the electrodes.

The report emphasizes the fact that the crate experiments involved putting the fish under unnatural conditions and that the results should be interpreted as indicating only relative efficacy of different conditions. Nevertheless, anyone reading the report may place other interpretation upon the data presented. For example, in tests of Series E 77 percent of the fish were retained in the live crate for a period of 1/2 hour while the electricity was on, whereas only 13 percent remained at the end of an equal period with the electricity off. Upon superficial consideration this might be interpreted as fairly successful. It is to be noted, however, that the test was for only a half hour. If the fish continued to leave the crate at the same rate, at the end of as short a time as 5 hours, only 7 percent would remain; in 9 hours less than 1 percent would remain.

The State report presents no final conclusion regarding the efficacy of the screen.

It is worthy of note that had the State been able to check the efficiency of the Hat 2 screen, and had they found that it was satisfactory, they still would not have had any basis for judging how successful a future installation at Pit 5 or any other site would be. This situation is due to the fact that they did not have records of the electrical characteristics that were responsible for success. In fact, neither they nor Burkey knew what were the controlling characteristics, to say nothing of knowing the required values of those characteristics. McMillan, Everest, and Holmes (1937) demonstrated that capacitance, and resistance are controlling factors. They presented the law of relation between these variables for the minimal response of fish, but did not determine what the values of these variables should be for application to a fish screen. Wales was aware of the fact that the distribution of potential gradient in the water is important; in fact, he improvised a means of grossly judging the relative distribution. Even the McMillan-Barnett meter with which Holmes assisted in the study of the field is calibrated only for alternating current; therefore, it also gave only relative values for different parts of the field. In keeping with his usual practice (see correspondence between Spencer and Holmes, quoted on pages 20 and 21) Burkey furnished no record of the characteristics of the impulses delivered by his "energizer". One graduated dial on

the electric screen and to compare the catches during short periods of screen operation with those of similar periods when the electric screen is shut off.

Holmes visited the screens soon after the first two were installed. He has conferred with Fry on several occasions and has made reports on previous work available to him.

It is understood that the study is still in progress. No report of recent accomplishments has been received. The best available indication of the results during the first two seasons is the following extract from a letter from Fry to Mr. O. G. Boden, U. S. Bureau of Reclamation, Antioch, California, dated August 24, 1946:

> "This is in reply to your request for more detailed information about the effectiveness of electric fish screens and about methods for screening the Delta-Mendota Canal.
>
> "We have found that electric screens offer no possibility of success except as deflectors. If a canal takes part of the water out of the river we feel that there is a possibility that electric screens can be developed to the point where they will effectively deflect fish back into the river which would otherwise enter the canal. We are not sure that they can be developed even this far but the chances look hopeful. Where practically the entire flow of a stream is going into the canal they offer little hope of success. The small salmon migrate downstream and all their instincts tell them to follow the current. If an electric screen gives them a shock they will bounce away from it. If there is a water flow tending to take them on down the river they tend to follow that current. But if there is no such current past the mouth of the canal they return to the screen and after being shocked a few times go right on through the screen.
>
> "Another feature which seems to play an important part is the size of the canal. If the canal is so large that its current pulls the fish up to the screen too often before the river current carries them to safety, they are apt to go through the screen.
>
> "Velocity of approach plays an important part in the effectiveness of electric screens. If the velocity exceeds one-half foot per second the screen will be ineffective no matter how ideal the installation may be in other respects. This holds true through February and March. Later in the season a slightly higher velocity might be permissible but we are not sure how much higher would be safe."

ELECTRIC SCREENS IN OTHER AREAS

This report so far has dealt exclusively with the electric screen on the Pacific Coast. Very little can be added regarding installations in other areas because of a lack of knowledge. As far as known, all of the installations in other areas have dealt exclusively with non-migratory fish. It is believed that in many cases such screens have been satisfactory.

One such installation is at Pymatuning Lake in Pennsylvania where the screen is placed on the top of a very low dam and is used to prevent the passage of fish--mainly carp--from a lower to an upper lake. It is reported to be thoroughly successful.

Another successful installation, in Wisconsin, is used in an artificial pond in which carp are retained. The purpose of this screen is to prevent the fish from fighting a slatted barrier that forms one side of the enclosure. This screen is illustrated in Burkey's folder entitled "Stopped by the Burkey Electric Fish Screen."

A third installation is reported to have eliminated the problem of fish clogging the screens at the Michigan City Generating Station. This screen and its operation is described in an article by F. L. Reinmann, entitled "Electric Fish Screen Keeps Intake Clear" in Electrical World, April 13, 1946, page 150.

Three additional screens are illustrated in the folder of Mr. Burkey's that is referred to above. Two more are shown on page 33 of the September 1947 issue of Civil Engineering.

These reports of the general success of the electric fish screen in other areas in contrast to its failure on the Pacific Coast may appear inconsistent. In this regard, it is to be noted that the application on the Pacific Coast has been primarily with migratory fish, whereas that elsewhere has been with resident species. In the one instance on the Pacific Coast of application to resident fish--at Yosemite Lake--it is reported to be successful. This one, like many others, however, has not been adequately checked.

SUMMARY OF HISTORICAL ACCOUNT

Mr. H. T. Burkey, who is credited with originating the idea of using electricity as a fish screen, applied for his first patent in that field in 1917.

In 1921 the Yakima County, Washington, Game Commission purchased rights to use Burkey's patents and a number of installations were made in Yakima and Chelan Counties at about that time.

Those early screens used A.C. or current from a Model-T Ford generator either with or without a spark coil. The electrode arrangement varied, but in general the direction of electric-current flow was across the ditch. Within a few years these crude screens had all disappeared.

Through the efforts of Mr. J. E. Yates, Professor F. O. McMillan made a study of the electric fish screen in 1926. His attention was devoted primarily to the response of fish to alternating current. He then applied his findings to experimental screens that he installed in hatchery ponds. In his published report (McMillan, 1928), in addition to giving the results of his experiments, he describes the effects of conductivity of the water upon the voltage required to shock fish; he also describes the distribution of voltage gradients in the water with various sizes of electrodes and distances between them. He finally makes recommendations for the design of electric fish screens. These recommendations included the use of A. C. and arrangement of electrodes in such a way that the electric current flows parallel to the direction of flow of the water.

During the years 1928 through 1932 the U. S. Bureau of Fisheries, represented by Shirley Baker and U. B. Gilroy, conducted experiments with the electric fish screen and made several installations. Upon the basis of a demonstration at the Delph Creek Hatchery and a test in the Tieton Irrigation Canal, they installed several of the Burkey screens in 1929. These installations later were changed from the Burkey design to the McMillan design. That is, the electrification was changed from pulsating direct current to uninterrupted alternating current, and the electrode system, originally of the so-called "grounded type", consisting of closely spaced, hanging electrodes plus a ground element that extended across the floor of the canal, was changed to two rows of widely-spaced, 6-inch diameter pipes, that were insulated from ground.

The success of the screens installed by Baker and Gilroy was judged primarily by the number of fish found in the canals after they were shut off at the end of the irrigation season. They at first were thought to be quite successful, but this attitude gradually changed and the screens finally were removed at the end of 1932.

Baker and Gilroy also applied the electric screen to controlling the passage of adult fish migrating upstream. Experiments conducted in the tailrace of the Gold Ray power plant in Southern Oregon were considered to be quite successful, except that sportsmen contended that

fish were being killed by the electricity. The experimenters at the time were not convinced that fish were killed. Their attitude was strengthened by the successful operation of an electric barrier for counting salmon on the Kvichak River in Alaska and an experimental barrier to adult fish in Green River in Washington.

Harlan B. Holmes later obtained convincing proof that alternating current could fatally injure adult salmon and other species and presented physiological explanation for such response to electric shock.

During 1934 and 1935 McMillan and Barnett made a study of the distribution of the potential gradient in water with various electrode arrangements and with both single-phase and three-phase circuits.

In 1936 Holmes and Morton conducted field tests on the Table Rock Ditch in Southern Oregon, where they applied the results of the laboratory work. They did not succeed in stopping the passage of salmon fingerlings that were migrating to the ocean.

In 1937 McMillan and Everest made use of the Table Rock field station for further field tests, including the use of 3-phase circuits. They, too, failed to obtain satisfactory results and concluded that alternating current never would be found satisfactory for use with migratory fish.

No further consideration has been given to the use of alternating current for electric fish screens.

As early as 1928 Burkey proposed the use of Voltage impulses. In 1929 he applied for a patent in which this feature was the major consideration. His patent specification describes the fact that alternating current cramps the muscles of the fish into a condition of tetanus in which condition the fish is unable to swim to get out of the electric field; whereas, with voltage impulses the fish retains the ability to swim. It is to be noted, however, that this patent was not issued until 1934 and the description in the specification did not become available until that time. For many years Burkey did not succeed in convincing others of the merit of voltage impulses.

Burkey first accomplished voltage impulses by interrupting D.C. by the use of a vibrating-pendulum contactor. This device was not able to carry the high current required for larger installations so was abandoned. Burkey later secured the services of the General Electric Company whose scientists developed and patented an electronic circuit which permitted selection of half-wave impulses of alternating

current at any desired frequency. Still later, Burkey devised an energizer that charged an electrical condenser to any desired voltage and then discharged it through the water. Such impulses could be delivered at any desired frequency. Installations made by Burkey since 1936 have employed this principle.

In 1937 McMillan, Holmes, and Everest conducted laboratory experiments with the condenser-discharge type of voltage impulses and worked out fundamental laws of its application to the electric fish screen. They did not, however, go far enough to apply their findings to field tests with the electric screen.

During 1936 and 1937 the Fishtite Electric Screen Company, who had obtained rights to market Burkey's screen in the Northwest, conducted both laboratory and field tests. They finally became convinced that the electric screen was not the solution to the problem of screening for migratory fish.

In 1936 the California Division of Fish and Game purchased one of Burkey's screens and tested it in an irrigation diversion near Yreka, California. It was found to be unsatisfactory and was removed. The screen originally sold on this occasion employed the half-wave type of impulse. Toward the end of the test it was changed to the condenser-discharge type.

Again in 1941, the California Division of Fish and Game tested a Burkey screen at the Mt. Shasta Hatchery. Again it was not considered as successful. Burkey, however, did not agree with the report prepared by the State.

In 1943 another test was made by the California Division of Fish and Game. This one, conducted at the intake to the Pacific Gas and Electric Company's Hat Creek Plant No. 2, was intended to serve as a basis for approval of a much larger installation at the Company's Pit 5 plant. The report of the test presents no conclusions as to the success of the screen. The Pit 5 electric screen was installed, however.

In 1945 the California Division of Fish and Game purchased three Burkey screens for test in large irrigation diversions near Mendota, California. These screens still are being tested and no final report is available. The latest report, in August 1946, was not especially encouraging.

Many favorable reports have been received regarding the success of a Burkey screen installed by the Sierra Pacific Power Company at its power plant on the Truckee River. Analysis of available data does not seem to justify such reports.

Due to a lack of information this report makes only brief reference to installations of Burkey screens in other parts of the country. It is understood that there are a number of them and that they deal primarily with non-migratory fish.

Two installations with non-migratory fish have been made in California at Yosemite Lake. A superficial attempt by the California Division of Fish and Game to check one of these was not conclusive. The sportsmen who purchased the screens consider them to be thoroughly satisfactory.

Only one trial has been made with the application of condenser-discharge impulse to adult salmon. This was made by Holmes for the U. S. Fish and Wildlife Service at the Mill Creek Hatchery in California. Holmes concluded that the screen did not succeed in blocking the upstream migration of the fish. Burkey may not agree with this conclusion.

In conclusion it must be stated that, though efforts have been made for 30 years to apply electricity as a screen for controlling the movement of fish, success has not been demonstrated when applied to migratory fish. In contrast to this it is probable that success has been achieved with resident fishes.

Despite the lack of success after so many years of application, it is believed that the possibilities have not been thoroughly exhausted. It, therefore, is recommended that further study be made.

DISCUSSION OF PROBLEMS AND RECOMMENDATIONS

SUCCESS OF PAST AND PRESENT SCREENS

Screening Resident Species

It is understood that Mr. Burkey has sold numerous screens that are in operation in various places throughout the country. Many of these that deal with resident fishes probably are thoroughly successful. In the preliminary stages of further research on the electric screen it would be advisable to learn the nature and success of as many as possible of these installations. Preliminary information could be obtained from Mr. Burkey and by correspondence with the owners of screens. It then would be desirable to visit many of the installations.

Information to be obtained would include: (1) the nature of electrical impulses, (2) the type and arrangement of electrodes, (3) the distribution of potential gradient in the water, (4) the rate and direction of water flow in the electric field, (5) the position of the screen with respect to the main body of water and alternate routes of travel such as a by-pass, (6) the kinds and sizes of fish involved, and (7) evidences of the success of the screen in accomplishing the intended purpose.

Much of this information could not be furnished by either Mr. Burkey or the owners of the screens. A trained observer with special equipment would be required for measuring the several electrical characteristics. The nature of such measurements is discussed in later sections. The evidences of success probably would be found to vary from mere opinions to definite proof. These should be carefully judged. The complete data finally should be analyzed to determine what combination of factors is responsible for success.

Screening Migratory Species

As far as is known, there are no electric screens now in use with migratory fish except the three being tested by the California Division of Fish and Game. (See page 32). Inquiry should be made of Mr. Burkey to determine if this impression is correct. Information should be obtained from the California Division of Fish and Game regarding the success of their tests. Consideration of further tests then should be based upon all available information. It probably will be found that further tests will not be justifiable until more experimental background becomes available.

When tests are made, they must not repeat the common error of relying upon demonstrations in hatchery ponds or under similar conditions where the fish do not react like normal migrating fish. Tests particularly should not involve repeated use of the same fish, because the fish soon learn, whereas under natural conditions a migrating fish has only one trial in which it must respond correctly or be carried through the screen.

Conclusive evidence of success can be obtained only under actual operating conditions and by direct observation. Records of success preferably should be in the form of a comparison of the counted numbers of fish diverted or by-passed, in contrast to the number that pass through the screen; or the comparison might be of the numbers of fish that pass the screen area with and without the screen in operation.

The latter procedure has the advantage that it does not require that all of the fish be caught. Instead of sifting all of the water that passes through the screen for the recovery of fish, a standard sampling procedure can be employed. The experimenter should recognize that many screen installations that would be satisfactory as a screen, might not permit reliable observations of the action of the fish. Note, for example (page 31) that Wales was unable to check the success of the Hat Creek installation because the water velocity below the screen was too high for the operation of nets.

TYPE OF ELECTRICAL STIMULUS

As a result of his experimental work in 1926 McMillan (1928) recommended the use of alternating current for fish screens. At least as early as in 1928 Burkey proposed the use of spaced impulses. The use of continuously applied alternating current now quite definitely has been abandoned in favor of the voltage impulses. Before discussing the relative merits of the two types of electrical stimuli and others that might be considered, it will be well to briefly review the physiology of muscular response to electrical stimulation.

Reaction of Muscles to Electrical Stimulation

If a skeletal muscle or its connecting motor nerve is stimulated by the passage of electric current, it may or may not contract and the extent of contraction, if any, will vary with the nature, duration, and intensity of the stimulus. The following are some of the laws of such reaction. Direct current stimuli will be considered first.

Strength of Stimulus

If a muscle is successively stimulated by passing direct current through it, starting with a very low voltage and progressively increasing the strength, the muscle will not respond until a certain strength of stimulus is reached. The first response will be a slight twitch of contraction at the start of the stimulus. As the stimulus is increased by applying higher voltage the resulting contraction will increase to a certain maximum beyond which no greater contraction will be obtained regardless of the increase in voltage. The least distinguishable contraction is called the "minimal" or "threshold" contraction and the stimulus that caused it is known as the "minimal" or "threshold" stimulus. Correspondingly the greatest contraction and the single stimulus required to produce it, are known as the "maximal" contraction and stimulus.

Rate of Change in Current

In addition to the contraction at the "make" of the direct-current stimulus, there is a similar but much weaker twitch of contraction at the termination or "break" of the stimulus. It is to be noted that between the "make" and "break" twitches of contraction, while the electric current is flowing at a constant rate, the muscle remains in a relaxed condition. In other words, the contraction of the muscle is the result of the change in rate of flow of electric current, not the amount of current flowing. An opposite effect of the rate of change of current is demonstrated by the fact that if the voltage applied to a muscle is gradually increased from below the threshold value, a voltage well above the threshold value can be reached without causing a contraction.

In the preceding paragraph it is stated that a muscle remains relaxed during the time that a constant current is flowing through it. This rarely is accomplished in practice when a high voltage is applied, because the passage of the current and other conditions cause variation in the resistance of the tissues, with the result that the current actually is not constant. The resulting variation in current causes minor contraction of the muscle similar to that resulting from alternating current as described in a later section.

Duration of Stimulus

The preceding discussion dealt with stimuli that were applied to the muscle for an ample period of time. Suppose now that the threshold voltage has been determined and that the muscle is successively stimulated at this voltage while the duration of stimulation is progressively decreased. In this way it would be found that there is a minimum limit of duration beyond which the stimulus is not effective. If similar procedure was repeated at higher voltages, it would be found that for each voltage a certain duration of application is required to produce a minimal contraction. The duration would be found to decrease exponentially as the voltage was increased. It further would be found that for different kinds of muscle and other excitable tissues this relation between strength and duration of stimulus varies greatly. In fact, physiologists have classified excitable tissues accordingly. As a unit of measure, they have chosen the time that voltage double the rheobasic voltage must be applied to produce a minimal contraction. To this value they have given the name "chronaxie". The following are some examples of chronaxie in the frog, expressed in milliseconds: skeletal muscle, 0.14 to 0.7; ventricular muscle of heart, 5; muscle of blood vessels, 1,000 to 2,000; and chromatophores 12,000 to 15,000. (From McMillan, Everest and Holmes, 1937).

Frequency of Stimulation

In the preceding discussion it has been assumed, though not clearly stated, that in any succession of stimuli, the interval between stimuli was sufficient to permit the muscle to contract and relax again before the next stimulus was applied. We now shall consider the effect of repeated stimuli at shorter intervals.

If a muscle is given a direct current stimulus, then at any time before it has completely relaxed from the resulting contraction it is stimulated again, upon application of the second stimulus it will start a second contraction. The resulting composite contraction will be distinctly greater than that resulting from a single stimulus of equal strength. A succession of such stimuli will cause a still greater and more prolonged composite contraction. Such response to a succession of stimuli is called "summation".

If a muscle is subjected to a succession of properly spaced stimuli continued for a sufficient period of time, the muscle will contract more and more with each successive stimulus until a certain maximum of contraction is reached and continuance of stimulation causes the muscle to remain contracted. This condition is known as "tetanus". If the individual stimuli are of sufficient voltage, the resulting tetanic contraction may be considerably greater than the maximum resulting from normal nervous stimulation.

The frequency at which stimuli can be applied without causing summation of contraction depends upon the rate of contraction of the muscles, which in turn is at least roughly proportional to chronaxie. This time interval has not been accurately measured for the skeletal muscles of fish, but it is believed to be approximately one-tenth of a second.

Sixty-cycle alternating current as used for commercial transmission of power is a common example of a succession of stimuli, that is, each cycle of alternation produces two stimuli. This frequency happens to be near the optimum frequency for efficiency in causing tetanus. It is of interest to note that as the frequency of alternating current becomes too high the stimulating effect decreased. At very high frequencies tremendous voltages can be applied without exciting muscles or other tissues. This probably is due to the fact that each individual impulse is of too short a duration to be effective.

Application of Various Electrical Stimuli to Electric Fish Screen

Direct Current

It has been generally assumed that continuously applied direct current is not a suitable stimulus for an electric fish screen. The

preceding discussion of the effect of prolonged direct-current stimuli is in keeping with this assumption. It will be recalled from that discussion that a muscle responds only to a rapid change in current. If a fish entered the field of continuously-flowing direct current, it would be subjected to increasing voltage (and current) as it progressed into the field, but it appears that the rate of change would be too slight to cause a muscular response.

In contrast to this analysis of the situation, it is to be noted that continuous direct current has been used successfully for electric fishing (Wolf, Ph., 1948). It further is of interest to note that in electric fishing and in laboratory work with direct current (Van Harreveld, A.,1938) fish show a pronounced tendency to swim to the positive electrode. It is possible that this reaction might be used to advantage in the electric fish screen. In any event, it would be advisable in future research, to give more attention to the possible use of direct current.

Alternating Current

As a result of his experimental work in 1926, McMillan (1928) recommended the use of continuously-applied alternating current. Upon the basis of further experience including field tests, McMillan and Everest (1937A) concluded that alternating current is not desirable. Holmes also reached the same conclusion upon the basis of both theory and experience. Particularly as applied to downstream migrants, alternating current is not satisfactory because it tetanizes the muscles of the fish, thereby making swimming impossible so the fish are carried through the screen by the flow of water. When applied to the larger fish, there is danger of breaking bones, tearing muscles, and otherwise injuring tissues. It, therefore, appears that continuously-applied alternating current is not worthy of further consideration. Advantage might be found, however, in the use of impulses derived from interrupting alternating current. This is considered in the next section.

Intermittent Impulses

At least as early as in 1928, Burkey proposed the use of intermittent electrical impulses. This feature was covered by his patent No. 1,974,444 for which he made application in 1929. Burkey first obtained impulses by interrupting direct current through a vibrating contactor. Later, using a circuit patented by the General Electric Company, he used half-wave alternating-current impulses. For the past 10 years he has used condenser-discharge impulses. McMillan, Holmes, and Everest (1937) experimented with condenser-discharge impulses and became convinced that they at least had merit over continuously-applied alternating current.

From the standpoint of muscle physiology the three types of impulses used by Burkey were essentially equal. The interruption of direct current was dropped from use as a result of difficulty with the vibrating contactor. The choice of condenser-discharge over half-wave impulses was mainly for financial reasons.

As indicated in the preceding discussion of muscle physiology, if the interval between successive electrical impulses is approximately one-tenth second or longer, the muscle so stimulated will respond to each stimulus independently. As a result, extreme and prolonged contractions are impossible and a fish subjected to such stimuli has control of its muscles for voluntary movement such as swimming. From this standpoint intermittent impulses are much better than alternating current for electric fish screens.

Condenser-discharge appears to be the ideal type of intermittent impulse from every standpoint. The ease with which such impulses of definite strength and duration can be produced has caused physiologists to make extensive use of them. In such work definite relations have been established for comparing the muscular response from direct current impulses and condenser discharge impulses.

The equipment required for producing condenser-discharge impulses of selected strength and frequency is simple. It consists essentially of the following (See McMillan and Everest, 1937B): (1) a condenser of readily computed capacity, (2) a source of direct current for charging condenser, (3) a resistance for controlling the rate of charging the condenser, and (4) a valve-type of electronic tube that will permit the condenser to discharge through the water of the fish screen whenever the condenser has become charged to the desired voltage. In practice rectified alternating current usually is the most convenient source of direct current for charging the condenser. The resistance in the charging circuit usually is variable so as to permit variation in the rate of charging and accordingly the frequency of impulses. A thyratron may be used as the valve to control the discharge of the condenser. Variation in the grid bias of such a tube provides adjustment in the voltage to which the condenser will be charged before discharging through the water. The size of condenser to be used is computed from the measured resistance of the electric field in the water through which it is to be discharged. From the work of McMillan, Holmes, and Everest (1937) it appears that the product of resistance in ohms times the capacitance in farads should be approximately 1 or 2 milliseconds. The voltage to which the condenser should be charged depends upon the electrode arrangement and the voltage required to stimulate the fish. The latter has not been adequately investigated.

The works of McMillan, Holmes, and Everest (1937) (also McMillan and Everest 1937) are recommended as sources of theoretical information regarding condenser-discharge impulses and their practical application to the electric screen.

Intermittent impulses of a type not previously tried might be found to have greater advantage. For example, each stimulus of an intermittent series might consist of two or more electrical impulses in rapid succession. Such stimulation would cause greater response as a result of the limited degree of "summation". A series of impulses of this type could be obtained by interrupting alternating current, or could be produced by specially designed generators.

Muscle Contraction vs. Pain Response

All of the preceding comments regarding physiological response to electrical stimulation have been limited to response in the form of muscle contraction. Muscle response is important in the consideration of the electric fish screen mainly because excessive contraction is not desirable. The preferred influence upon the fish is to produce an unpleasant sensation such as pain. Electrical stimulation definitely causes pain in humans. It is not known to what extent a sense of pain is developed in fish, but their response to electrical stimulation indicates that they have some such sensation. We are not justified, however, in concluding that there is an exact parallel in fish to the pain response in humans when stimulated by electricity.

A more important point is that the laws of muscular response to electrical stimulation are not necessarily paralleled in the case of pain response. An example of this was demonstrated by McMillan, Holmes, and Everest in connection with their work in 1937. It was not included, however, in their report. The demonstration was as follows:

An experimenter placed one hand in the water between two plate electrodes and slowly opened and closed his fist while alternating current was slowly increased in voltage. As the voltage was increased, involuntary contraction of the muscles finally made voluntary movement of the fingers impossible but the pain sensation was not serious. The same experiment was tried with condenser-discharge impulses at a frequency of approximately five per second. In this case it was possible to continue movement of the fingers as the voltage was increased until the intensity of the pain reaction became unbearable.

Experiences of this nature should cause future experimenters to use caution in judging stimuli in terms of their effect upon muscle contraction, and in judging effect upon fish in terms of human reactions.

ELECTRODE ARRANGEMENT AND DISTRIBUTION OF POTENTIAL GRADIENTS

Past Practices

Throughout the history of the electric fish screen it has been recognized that the electric field should be graduated so that as a fish penetrates farther into the field, it receives a progressively greater shock. Such graduation also was recognized to compensate for the difference in voltage required to stimulate fish of different sizes. In the earliest installations an effort was made to accomplish a graduated field by applying progressively higher voltages to a succession of electrodes. It later was recognized that the natural distribution of voltage gradient with one set of properly arranged electrodes gave a graduated field.

Since McMillan's work in 1926, it has been accepted—though not necessarily correctly—that the direction of flow of electric current should be in general parallel to that of the water.

There have been two prevailing electrode arrangements used to accomplish these desired conditions of graduation and direction. One, referred to here as the Burkey design, consists of a single, suspended row of closely-spaced, small rods or equivalent to form one electrode, and, as the second electrode, a small pipe or equivalent resting on the bottom, paralleling the row of rods. The other design referred to here as the McMillan design, consists of two rows of well-spaced, large, cylindrical electrodes, with all electrodes within a row connected in parallel, and the electric current flowing between rows. The Burkey design, on account of one electrode resting on the bottom, sometimes is referred to as a "grounded" system; whereas, the McMillan design, in which the electrodes have actual contact only with the water, is referred to as an "insulated" system.

In both designs of electrode system the only portion of the field that is of interest (in preventing the passage of fish from the upstream side) is that in the area upstream from the hanging electrodes. That is, the success of the screen depends upon the fish stopping before they reach the hanging electrodes. In the Burkey design, this area theoretically is in the direct field between the two electrodes. In the McMillan design, the field in this area theoretically is created only by the "bulging" of the electric field into this area as a part of the current follows a much curved course in flowing from electrodes of one row to those of the other row (See McMillan, 1928, Figure 10).

Actually the field in the area in which we are interested is not as different for the two arrangements as this theoretical presentation would make it appear. This is due to the fact that normally the ground or other material of the bottom and sides of the water course is a better conductor than the water and much of the current flows through it. In fact, the ground could be said to serve essentially as an electrode, with the result that for both designs, in the area upstream from the hanging electrodes the prevailing flow of current is between ground and the hanging electrodes. With respect to the influence upon the fish, we are not concerned with the fact that in the McMillan design there is an electric field between the two rows of electrodes and from the back row to ground. It is worthy of note, however, that due to the relatively small size of the Burkey ground electrode, there usually are high potential gradients in the water near it. This may or may not be advantageous.

Effect of Current through Ground on Electric Field.

In the preceding paragraph the influence of ground upon the Burkey and McMillan design of electrode arrangement was discussed. This is one example of the varied effect that the conductivity of surrounding materials may have on the field of the electric screen. Another example (see page 30) was Burkey's first electrode system at the Hat Creek screen, in which no electric field was produced in the desired area. Variation in the conductivity of materials in the electric field and their distances from the electrodes correspondingly vary their influence upon the electric field in a manner and to an extent that is not entirely predictable.

In addition to distorting the electric field, the flow of current to ground and other materials near the electrodes is responsible for tremendous losses of electrical energy that add nothing to the success of the screen. It is estimated that in many cases 90 percent or more of the energy is lost in this way. These conditions should be considered in each installation, and study should be directed toward eliminating, or at least minimizing them. Holmes has considered the possibility and advantages of lining the water course at the site of the screen with some highly resistant material. He has visualized, for example, placing in such an insulated ditch section, an electrode system of the Burkey design but having the bottom electrode greatly increased in size so as to eliminate the excessive potential gradients near it. It is believed that the width of the bottom electrode should be a function of the depth of water; in other words, a function of the area of the hanging electrode system.

In regard to possible insulating materials, it is of interest to note that McMillan and Barnett (1935) found the concrete used in Bonneville Dam to have a resistance of the same general magnitude as the water in which test samples were immersed. Measurements of potential gradient made by Holmes at the Granada screen indicated that the concrete of the ditch section in which the screen was installed had a resistance much higher than the water. Holmes found that two inches of fir wood in water had no significant insulating effect. It is suggested that asphalt paving be considered as a possible insulating material.

Measurement of Potential Gradients

McMillan (1928) presented a basic discussion of the distribution of potential gradients in the water between one or more pair of electrodes. McMillan and Barnett (1935) made extensive measurements of the potential gradient with certain, rather limited variations in electrode arrangement, mainly of the McMillan design. There are no well recorded measurements with the Burkey design of electrode system.

From the preceding varied comments regarding electrode arrangements and electric fields it should be obvious that further study should be made of the distribution of potential gradients in the water and that field installations should be checked.

Meter for Measuring Potential Gradients

The first requirement for the study of the electric field in the water is a meter for measuring the potential gradients. Barnett (1936) adequately described the fact that a meter for this purpose must not draw current from the water for its operation. The McMillan-Barnett meter is available for such use. However, it is calibrated only for alternating current. The meter does give readings with condenser-discharge impulses, but does not truly indicate the "crest" voltage as it does for A.C. It is believed that the reading for a succession of condenser-discharge impulses of a given voltage is a function of the frequency of impulses and the time constant of the circuit. It should be possible to calibrate the meter for certain values of these two factors. Consideration should be given, however, to the possibility of securing or constructing a meter that eliminates these variables. For field use, on account of the difficulty of holding probe electrodes steadily at one place in the water, it is essential that the meter be direct reading, in contrast to requiring adjustment such as balancing a resistance bridge to a zero reading.

DIRECTION OF FLOW OF ELECTRIC CURRENT

As a result of his work in 1926, McMillan (1928) recommended that the general direction of flow of electric current be parallel with the flow of water through the screen. Without much further consideration this recommendation has been accepted and followed. It is believed that this item should not be so lightly passed over. Theoretical justification can be presented for this and for other orientation of the field.

It is to be recalled from McMillan's work that the degree of shock received by a fish in a field of uniform gradient is proportional to the distance that the electric current travels in going through the fish. If the fish is oriented in the field with its length parallel to the lines of current flow, so that the electricity flows the full length of its body, the shock will be much greater than if the fish is at right angles to the lines of current flow so that the current flows across the fish's body. McMillan further observed that when fish were subjected to a moderate shock, they oriented their bodies at right angles to the direction of flow of electricity so as to receive the least shock.

Consider now the case of an electric screen with the direction of flow of electricity parallel to that of the water flowing through the screen, and let it be assumed that a fish migrating downstream would be drifting with the current while heading upstream. Upon receiving the electric shock, the fish might swim straight upstream so as to leave the electric field, or it might turn to one side and receive a lesser shock. If it did start turning, its tendency would be to make a 90 degree turn and thus receive the least possible shock for the particular point in the electric field. However, while the fish was turning to one side, particularly if it turned 90 degrees, the movement of the water would carry it farther into the electric field where the shock would be greater. Nevertheless the fish still would receive an even greater shock if it attempted to turn so as to swim back upstream out of the electric field. The final tendency would be for the fish to drift through the electric field despite the fact that in so doing it eventually would receive a much greater shock than if it had turned back. Much the same trend of events might be expected regardless of the orientation of the fish as it entered the field.

The above trend of events did not consider the fact that the fish probably would be swimming as it was being carried by the current. This might carry it to safety in a strategically located bypass.

Let us now modify the situation by assuming that the electric field is oriented so as to have the direction of flow of electricity at right angles to the flow of water. In this case the fish would be inclined to orient themselves to be parallel with the direction of water flow. This would be fine if the fish entered the field tail first or if it turned to reach such position, but a fish that entered the field head first would receive least shock at any instant if it continued moving into the field.

The theoretical cases cited above involved the assumption that water was flowing through the screened area. The ideal location for an electric screen is where there is no significant current of water or where the direction of flow is essentially parallel with the line of electrodes. Under such conditions it would seem preferable to orient the electric field so as to induce the fish to swim across the face of the protected area.

The preceding discussion does not present a solution of the problem of orientation of electric field. It is not intended even to be a complete discussion of the problem. It will have served its purpose if it indicates the existence of problems and the fact that they probably cannot be solved by theory alone, but will require field observations. Here again the experimenter is warned not to rely upon hatchery ponds or similar unnatural conditions for final observations.

WATER VELOCITY AT SCREEN

One of the most important requirements for successful screening, and the one most commonly violated, relates to the velocity of water at the screen. This applies to all types of fish screening for downstream migrants, but is more important in the case of the electric screen than for wire mesh screens. When a fish approaches a screen and finds its progress blocked, the success of the screen depends upon the fish stopping or at least changing its direction of travel. If the velocity of water through the screen is too great, such action on the part of the fish is impossible. The prevailing experience with mechanical screens is that the velocity in diversions is too great for successful screening. As a result the canal usually must be materially widened at the site of the screen. The permissible velocity of approach to a screen is dependent upon the size and species of fish, but in general for salmon and trout, 1½ feet per second is considered to be a maximum and under one foot per second is preferred. That is, such velocities have been found satisfactory for mechanical screens. Still lower velocities would seem desirable for the electric screen.

LITERATURE

Holmes has a bibliography of approximately 150 references on the combined subjects of electric fish screen, electric fishing, reaction of humans to severe electric shock, response of fish to electrical stimulation, and muscle physiology. Many of these references are in foreign languages, principally French and German, and have not been completely translated. Only the more important articles will be reviewed here. The entire bibliography with abstracts of most of the articles will be available to anyone who may undertake further research.

A review of the literature of electric fish screens has revealed that this device has not been extensively used in other countries. It further is evident that no real contributions have been made in the design or application of the electric screen by others than the workers mentioned in the earlier sections of this report. Most of the articles dealing specifically with the electric fish screen are popular accounts of installations that are neither authoritative nor informational. Such articles are of interest mainly from the standpoint of the unjustified claims of success that many of them contain. The following are popular articles relating to Burkey's installations during the past ten years: American Weekly, 1946; Case, J. O., 1938; Civil Engineering, 1947; Electrical West, 1942; Electronics, 1946; Electronics Digest, 1946; Evening Gazette, 1946; Power, 1945; Reinmann, 1946; Savage, 1936; Sportsmen's Review, 1936; Welch, T. J., 1943; Western Construction News, 1947; Westinghouse Engineer, 1946; and Westinghouse Newsfront, 1945.

From the literature on electric fishing it is found that this method of fishing has been used on a small scale in several European countries for nearly twenty years and recently has been used in this country by fishery biologists. Both direct and alternating current have been used with various electrode arrangements. Literature in this field may contain worth while accounts of the reaction of fish to various types of electrical stimuli. See particularly Kurt Smolian (1944), David S. Shetter (1947), and Ph. Wolf (1948).

There are many references in the literature on the general subject of the reaction of fish to electrical stimuli, that is, the reaction of the fish itself rather than the reaction of its individual muscles. Such literature is a valuable source of basic information that would serve as a basis in the planning of future research. This literature is to be found under the classification of response of fish to galvanic stimuli, electronarcosis, electrotropism, electrotaxis, etc. The following references have been selected for variety of approach and their further reference to literature. Holzer, 1931; Okada, 1929; Regnard, 1931; Scheminzky, 1924; Steinhausen, 1921; Van Harreveld, 1938; and Van Harreveld, Plesset, and Wiersma, 1942.

Much of the preceding section on muscle physiology has been written from memory upon the basis of a general background of knowledge and without specific reference to literature. Therefore no attempt will be made to furnish complete references on the subject. The general subject of muscle physiology is covered by physiology text books, but they as a rule do not deal with the response of muscles to varied electrical stimuli. The two following references will be found of particular interest: Evans, 1928; and Solandt, 1936.

PATENT SITUATION

Burkey Patents

Mr. H. T. Burkey made his first application for patent on September 28, 1917. The patent was issued on June 11, 1918 as patent No. 1,269,380 with the title of "Electric Fish-Stop." This patent deals with the basic principle of electrifying the water to prevent fish from passing, and the use of a succession of electrodes at successively higher voltages to produce a graduated field. It mentions the use of only alternating current.

On May 18, 1918 - while his first patent was pending - Burkey applied for a second patent which was stated as representing improvements. The patent, No. 1,292,246, entitled "Electric Fish-Stop", was issued on January 21, 1919. The principal purpose of this patent seems to have been to cover the feature of arranging the electrodes on opposite sides of the water course in such a way as to cause the electric current to flow diagonally across the channel so as to subject the entire length of the fish to the electric current.

On March 29, 1922 Burkey applied for a third patent. It was issued on November 11, 1924 as No. 1,515,547, with the title of "Electric Fish Stop". This patent relates to the arrangement and support of electrodes, primarily to hinged support that permits electrodes to swing out of the way to allow drifting debris to pass. It proposes the use of three rows of electrodes, with alternate electrodes within rows of opposite polarity and voltage on successive rows increased to produce graduated field.

Burkey applied for a fourth patent on July 12, 1928. The patent, No. 1,882,432, was issued on October 11, 1932, with the title of "Fish Diverter for Irrigation Ditches, Flumes, Natural Waterways, and the like". The stated objectives are to improve means of applying the electric current, specifically by utilizing metal trash racks as one electrode. A further objective is to "...

provide a construction wherein electric current will flow lengthwise through the body of a fish and in the line of flow of the water and progress of the fish." The five formal claims all relate to causing the electric current to flow in a general direction parallel with the flow of water.

Burkey applied for his fifth and last patent on June 12, 1929. It was issued on September 25, 1934, as No. 1,974,444, with the title of "Method of an Apparatus for Electrically Diverting Fish." This patent deals primarily with the use of current impulses and presents an excellent discussion of that subject. All but 2 of the 30 formal claims include this item of pulsations. The two remaining claims relate to an electrode arrangement that may be worthy of consideration.

Baker Patents

Mr. Lin E. Baker applied for a patent on February 7, 1927. The patent, No. 1,690,440, with the title of "Fishing Apparatus", was issued on November 6, 1928. The description and formal claims relate to driving fish into a net by electricity and stunning them so they may be conveniently removed.

On April 7, 1936 Baker applied for a second patent, which was issued on February 7, 1939 as No. 2,146,105 with the title of "Method and Device for Handling and Conservation of Fish and the Like." The patent describes a variety of applications of the electric screen, including use with starfish, etc. that crawl on the bottom, and means of permitting fish to pass in one direction but not in the opposite direction. It also relates to the use of sound as a warning signal in combination with an electric field. From the electrical standpoint, the most important feature is the use of alternately-operative, overlapping, electric fields.

Patented Circuit

The circuit used at one time by Burkey for providing spaced, half waves of alternating current was covered by patent No. 2,016,147 issued on October 1, 1935 to Cramer W. LaPierre, Milton S. Mead, and Francis B. Menger, and assigned to General Electric Company. No attempt will be made here to describe either the circuit or the patent claims. The specification makes no mention of fish screens.

Discussion

The preceding record of patents on the electric fish screen is presented for the dual purpose of adding to the history and development of the device and to indicate what problems of infringement of existing patents might arise in future use of the electric screen.

The writer does not presume to be an authority on patents. He understands, however, that a patent grants to the inventor the exclusive right for a period of 17 years to use or license the use of his invention as described in the formal claims listed in the patent specification. It also is understood that, although the formal claims are to be interpreted in the light of the disclosures in the descriptive part of the specification and its drawings, any feature disclosed in the descriptive part of the specification is not protected by the patent unless formally claimed. It further is understood that issuance of a patent containing a certain claim is not proof of validity of that claim. As there are certain specified conditions, such as being the true inventor, that the patentee must meet, the patent or its individual claims are subject to contest in the courts where it may be shown that such conditions were not fulfilled. A presumed infringement also is subject to the interpretation of the courts.

Of the seven patents described above, the first three issued to Burkey and the first one of Baker's have expired, leaving four that are of interest from the standpoint of possible infringement.

It is possible that further consideration might be given to impulses obtained by interrupting alternating current and producing such impulses might infringe patent No. 2,016,147, which is controlled by General Electric Company. The possibility of such infringement should be considered but it is believed that other satisfactory circuits could be found.

Baker's second patent (No. 2,146,105) conceivably might become of interest from the standpoint of overlapping electric fields. Although McMillan and Barnett (1935) (See page 53) worked on overlapping electric fields by the use of three-phase alternating current in 1935, at least three years before Baker applied for his patent, this does not seem to invalidate Baker's patent because the results were not put to use, they were not known to Baker, and they were not published.

It seems possible, though not probable, that the Federal Government received rights to Baker's second patent in a license

that Baker granted for his first patent. This license, granted in February or March 1932 and referring to patent No. 1,690,440, states in part "...Lin. E. Baker agrees and does hereby grant to the United States Government,...., a license to employ the device described and claimed in said patent and in any other patent granted upon or covering said invention..." (underlining added).

Burkey's patent No. 1,882,482, which does not expire until October 1, 1949, covers the feature of arranging the electric field to have the electric current flow in a direction parallel with the flow of water. This feature has been considered desirable in all recent installations. McMillan recommended this feature as a result of work done more than two years before Burkey's application for patent. It is possible that Burkey's knowledge of this work was such that it would invalidate his claims.

The most important patent to be considered is Burkey's latest one, No. 1,974,444, which is effective until September 25, 1951. This patent appears to adequately cover the feature of voltage impulses, which is considered to be essential to the success of the electric screen. It therefore should be anticipated that payment of royalties or other arrangement with Mr. Burkey would be required for use of this feature until the patent expires in 1951.

SUMMARY OF RECOMMENDATIONS

Despite the fact that the electric fish screen has been in use for thirty years and has been the subject of study for the greater part of that time, there still is uncertainty as to its effectiveness in blocking the passage of fish. There particularly is doubt in the case of application to migratory fish. This uncertainty should be removed by checking existing installations, by reviewing the work being done by the California Division of Fish and Game, and if found necessary, by conducting further tests.

If it is found that some existing installations are accomplishing the desired results, such installations - possibly also some that are not successful - should be carefully analyzed to determine what features are responsible for their success. Features that should be considered have been discussed in preceding sections.

Regardless of the success or failure of past and present installations, it certainly is true that the possibilities of the electric screen have not been adequately explored. Application to resident fishes alone, with which success is most promising, appears to justify further study. Efforts to improve the electric screen are further justified by the fact that there are various situations, such as deeply submerged outlets from reservoirs, for which no other method of screening has been found satisfactory.

Further research with the electric screen should start with a thorough knowledge of past experience and present status of the electric screen. This report is intended to furnish a start toward such background. A further prerequisite is an adequate knowledge of certain phases of fisheries biology, physiology, electricity, and engineering. As all of these qualifications are not apt to be found in one man, experts in these four fields should take part in future research, at least in a consulting capacity.

It is recommended that future research include laboratory study on the reaction of fish and muscle tissues to various electrical stimuli. This should include variations in stimuli that previously have not been considered. Such laboratory study should be followed by field tests in which the results of laboratory work should be confirmed and applied to best advantage. Finally, provided success has been accomplished, the features responsible for success should be established and clearly stated for use in planning and checking future installations.

It will be necessary to acquire, possibly by design and construction, special instruments for measuring, (1) the frequency of impulses, (2) peak voltage of condenser-discharge impulses, and (3) potential gradient in the water. An effort should be made to develop simple and inexpensive equipment for producing the preferred electrical stimuli. As power lines frequently are not conveniently available, consideration should be given to inexpensive means of generating the required electricity by paddle wheel or other water power.

Due consideration should be given to the rights of others who have contributed to the development of the electric screen, but to the extent that further advancement is made at government expense, efforts should be made to permit general use without patent restrictions and the expense of high royalties.

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